

# THE AMERICAN MINERALOGIST

JOURNAL OF THE MINERALOGICAL SOCIETY OF AMERICA

Vol. 23

JULY, 1938

No. 7

## PETROLOGIC RESULTS OF A STUDY OF THE MINERALS FROM THE TERTIARY VOL- CANIC ROCKS OF THE SAN JUAN REGION, COLORADO<sup>44</sup>

ESPER S. LARSEN, JOHN IRVING, F. A. GONYER, AND

ESPER S. LARSEN, 3RD

*Harvard University, Cambridge, Mass.*

*(Continued from p. 257 (April, 1938))*

### 8. ORTHOCLASE

ESPER S. LARSEN AND ESPER S. LARSEN, 3RD

#### OCCURRENCE AND ASSOCIATIONS

Orthoclase and related alkalic feldspars are not abundant in the lavas of the San Juan region, except in the groundmass. The sanidine variety of orthoclase is present as phenocrysts in about half the rhyolites and rhyolitic quartz latites of the Potosi volcanic series and in most of the rhyolite of the Hinsdale formation. Local rhyolite bodies of the Hinsdale formation, such as the obsidian of the No Agua volcano, New Mexico, contain no sanidine phenocrysts. Sanidine phenocrysts rarely constitute over 15 per cent of a rock and in most instances much less than that. Nearly all the sanidine-bearing rhyolitic rocks of the Potosi series carry plagioclase phenocrysts (chiefly oligoclase or oligoclase-andesine), whereas those of the Hinsdale formation contain little or no plagioclase. Quartz phenocrysts are present in over half of the quartz latites that carry sanidine phenocrysts; they are present in all of the Hinsdale and Sunshine Peak rhyolites, but they are not common in the rhyolites of the Potosi series.

Biotite is present in all the rhyolitic rocks that possess sanidine phenocrysts, and it is commonly the chief or only ferro-magnesian silicate in such rocks. Hornblende associated with biotite, and rarely with augite and biotite, is present in most of the quartz latites that carry sanidine. Rhyolitic rocks with appreciable amounts of augite, but without hornblende, very rarely contain sanidine phenocrysts, although

<sup>44</sup> Published with the permission of the Director of the U. S. Geological Survey, Washington, D.C.

such rocks have essentially the same chemical compositions as those with phenocrysts of hornblende, sanidine and other minerals.

Sanidine also occurs as an erratic constituent, probably as foreign crystals, in some of the quartz latites, andesites and basalts. Some of the Fisher quartz latites and andesitic quartz latites contain rather abundant sanidine crystals as large as 20 millimeters or more across. They are associated with equally large phenocrysts of plagioclase, mafic minerals and, in some rocks, quartz. These sanidine crystals are much rounded from resorption, and in many of the rocks they are surrounded by a layer of sodic plagioclase, similar to the orthoclase of the rapakivi granites.

Sanidine is also present in some of the andesites and andesite-basalts of the Hinsdale formation, where it is associated, in most cases, with quartz, plagioclase with very sodic cores and calcic borders, pyroxene and olivine. It is much resorbed. The rock of Ortiz Peak, near Tres Piedra, New Mexico, is a good illustration of this, and a partial analysis of the orthoclase from that rock is shown in Table 11.

#### DESCRIPTION

All the potash feldspar phenocrysts, even the erratic phenocrysts in the andesites and basalts, are glassy sanidine. The rhyolite of the Hinsdale formation, the rhyolites of the Valles Mountains, New Mexico, and the Sunshine Peak rhyolite show the blue iridescence of moonstone.

TABLE 10. ANALYSES OF SANIDINE PHENOCRYSTS FROM THE LAVAS OF THE SAN JUAN REGION BY F. A. GONYER

	DN2017	SCxx	SC906
SiO <sub>2</sub>	65.06	64.39	66.08
TiO <sub>2</sub>		none	none
Al <sub>2</sub> O <sub>3</sub>	19.24	19.23	19.34
Fe <sub>2</sub> O <sub>3</sub>	0.30		0.14
FeO		0.54	
MnO		none	none
MgO	0.09	0.08	none
CaO	0.28	0.60	0.70
Na <sub>2</sub> O	2.66	4.04	6.06
K <sub>2</sub> O	11.86	10.25	7.36
H <sub>2</sub> O—	0.04	0.08	
H <sub>2</sub> O+	0.34	0.31	0.16
	99.87	99.52	99.84
Sp. Gr.	2.564	2.589	

The localities of the specimens are given under Table 11.



The blue iridescent sanidines have over 50 per cent of the albite molecule. A careful examination of these with a microscope shows that they contain very thin lamellae of intergrown albite, which are believed to be due to unmixing. The other sanidines appear to be homogeneous.

Complete analyses of three of the sanidine phenocrysts have been made and are given in Table 10. Alkali and lime determinations have been made on three additional sanidine phenocrysts, alkali determinations on five others, and lime and alkali determinations on all the rocks from which the 11 sanidines were separated. The alkali and lime contents of the 11 sanidines, and of the rocks from which they came, the anorthite content of the plagioclase phenocrysts of the rocks, and the optical properties of the sanidines are given in Table 11.

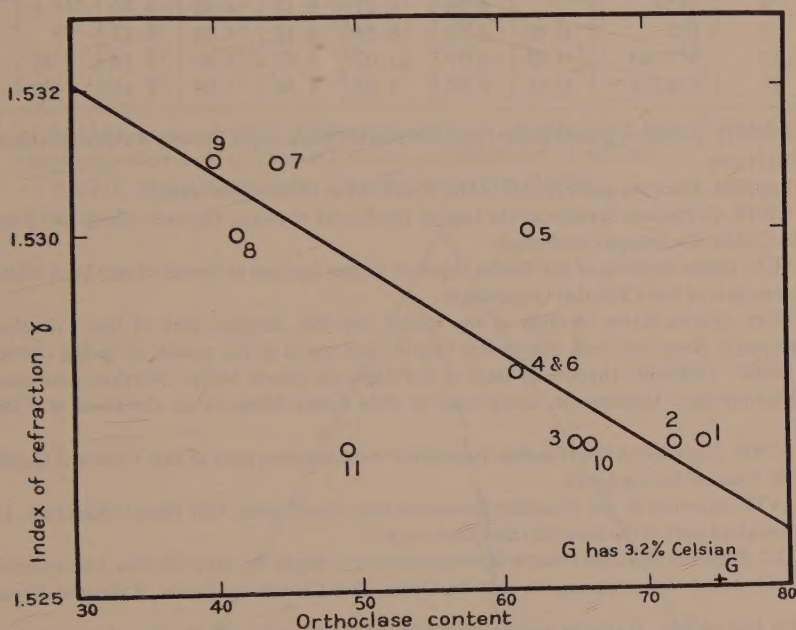


FIG. 28. Relation between  $\gamma$  index of refraction and orthoclase content of sanidines from the lavas of the San Juan region.

The indices of refraction of the sanidines, given in Table 11, were determined with sodium light and are accurate to  $\pm 0.001$ . In Fig. 28,  $\gamma$  is plotted against the Or content of the sanidine. Nine of the sanidine points in this figure determine a straight line such that none of the nine is distant from the line by more than the limit of error of the determination of the indices. Points in the figure corresponding to sanidines from rocks 5 and 11 (Table 11) are erratic for some reason, perhaps due to some different heat history. The CaO content does not appear

TABLE 11. ALKALI CONTENT OF SANIDINE PHENOCRYSTS AND OF THE ROCKS IN WHICH CRYSTS, AND THE OPTICAL

Number on figures	Rock	Sanidine			Rock			Añ in plagioclase
		CaO	Na <sub>2</sub> O	K <sub>2</sub> O	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	
1	DN2017	0.28	2.66	11.86	3.46	3.49	3.98	34
2	Lag 1059		2.78	11.32	3.68	3.60	4.05	26
3	C2018		3.78	10.72		3.34	5.18	29
4	SCK		4.01	9.71	0.76	3.22	5.40	26
5	SCxx	0.60	4.04	10.25	1.70	3.80	5.25	37
6	U3027		4.26	10.35	1.08	3.70	6.15	29
7	SC906	0.70	6.06	7.36	0.39	3.80	5.20	
8	SV78		6.26	6.77	0.14	4.49	4.40	6
9	JL7	0.40	6.55	6.56	0.12	4.34	4.22	
10	SC1740	0.49	3.57	11.07	4.03	3.59	3.74	45
11	NM213	0.61	5.32	7.61	7.40	3.04	2.18	30

DN2017. Alboroto quartz latite from Del Norte Quadrangle. Quarry 4 miles southeast of Del Norte.

Lag1059. Alboroto quartz latite. Alder Creek in the Creede Quadrangle.

C2018. Cavernous rhyolite at the base of the Piedra rhyolite. Between Sheep and Four Mile Creeks. Cochetopa Quadrangle.

SCK. Latite-rhyolite of the Piedra rhyolite. Upper horizon at South Clear Creek Falls. Eastern part of San Cristobal Quadrangle.

SCxx. Quartz latite obsidian of the Piedra rhyolite. Eastern part of San Cristobal Quadrangle. Road on north side of Rio Grande and north of the mouth of Spring Creek.

U3027. Tridymite rhyolite at base of the Alboroto quartz latite. Northwestern part of Uncompahgre Quadrangle, along road to Pine Creek Mesa at an elevation of 8350 feet.

SC906. Rhyolite of the Hinsdale formation. Northeastern part of San Cristobal Quadrangle. Head of Spring Creek.

SV78. Rhyolite of the Hinsdale formation from small cone, Old Baldy Mountain, in northeastern part of the Summitville Quadrangle.

JL7. Rhyolite of Valles Grande Mountains west of Santa Fe, New Mexico. One quarter of a mile below Seven Springs in Cebolla Creek, about 1 mile southeast of Rancho Rhea.

to be the cause. Barium oxide was not determined and it may be responsible. If  $\alpha$  and  $\beta$  indices were plotted in the same way, the results would be similar. In general, the Or content of sanidines can be determined to  $\pm 10\%$  by determining one index of refraction to  $\pm 0.001$ . The curve in Fig. 28 agrees well with that given by Winchell.<sup>45</sup> Neither 2V nor the extinction angle ( $\alpha \wedge a$ ) varies regularly with Or content.

The one true sanidine discussed in Spencer's<sup>46</sup> recent paper on the potash-soda feldspars contains over 3% of the celsian molecule and its  $\gamma$  index falls below the curve here presented (G of Fig. 28).

<sup>45</sup> Winchell, A. N., Studies in the feldspar group: *Jour. Geol.*, vol. 33, p. 720, 1925.

<sup>46</sup> Spencer, E., The potash-soda-feldspars. I. Thermal stability: *Min. Mag.*, vol. 24, no. 156, plate XVIII specimen G, 1937.



THEY OCCUR, THE ANORTHITE CONTENT OF THE ACCOMPANYING PLAGIOCLASE PHENOPROPERTIES OF THE SANIDINES.

Sanidine			$\alpha$	$\beta$	$\gamma$	2V	$\alpha/\wedge a$
Or	Ab	An					
74	24	1½	1.522	1.527	1.527	Small	7°
72	25		1.522	1.527	1.527	10°+?	7°
65	32		1.522	1.527	1.527	10°-20°?	8°
61	36		1.523	1.528	1.528	20°±?	13°
62	35	3	1.525	1.530	1.530	41°	17°
61	36		1.522	1.528	1.528	34°	9°
44½	52	3½	1.525	1.530+	1.531	41°	11°
41½	55½	3	1.525	1.530	1.530	20°-30°?	10°
40	57	2	1.525	1.531	1.531	20°±?	9°
66	31	2½	1.521	1.527	1.527	21°	11°
49	48	3	1.521+	1.527	1.527	?	8°

SC1740. (same as 1683). Fisher latite-andesite. Northeastern part of San Cristobal Quadrangle near head of Mineral Creek at an elevation of 11,400 feet.

NM213. Basalt. Ortiz Peak, near No Agua, New Mexico.

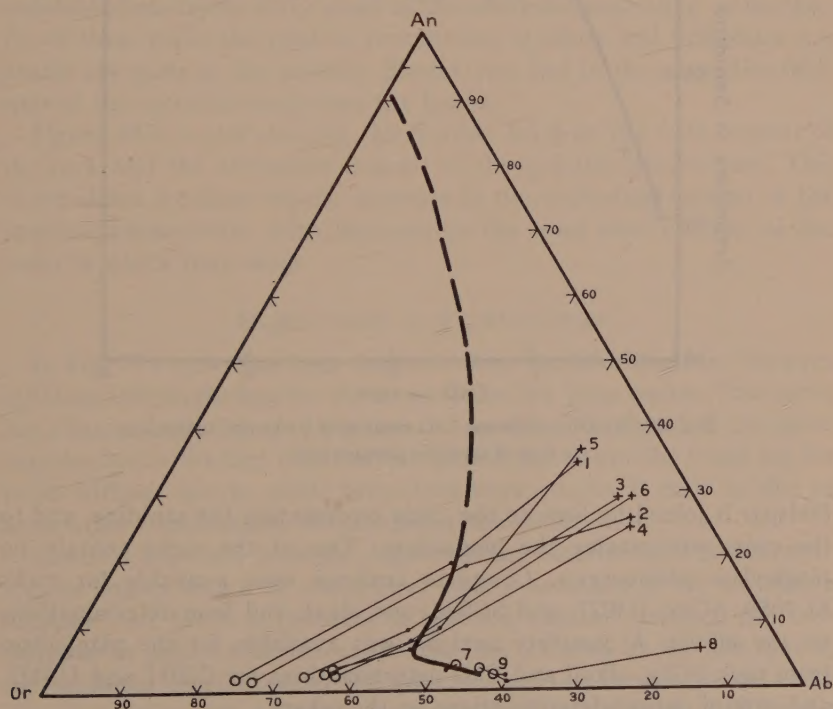


FIG. 29. Relation between sanidine phenocrysts, plagioclase phenocrysts and normative feldspars of the enclosing rocks.

Sanidine is represented by circles, plagioclase by crosses and rock by dots.

The sanidines are all low in lime and carry a maximum of  $3\frac{1}{2}$  per cent of anorthite. They range from 24 to 57 per cent in albite content. There is no clear relation between the percentages of anorthite and albite.

In Fig. 29 the compositions of the normative feldspars, the sanidine phenocrysts and the plagioclase phenocrysts of nine rocks are plotted on a triangular diagram. For each rock the dot representing the normative

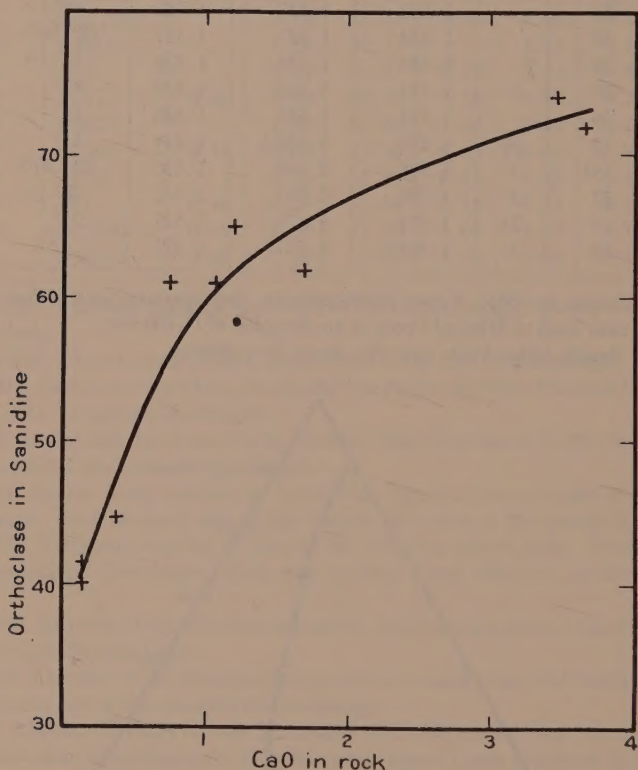


FIG. 30. Relation between CaO content of rocks and orthoclase content of sanidine phenocrysts.

feldspar is joined by lines to the circle representing the sanidine, and to the cross representing the plagioclase. Two of the rocks contain no plagioclase phenocrysts. Complete analyses were available for rocks SC1059, SCxx, U3027, and SC906; and alkali and lime determinations on the others. A complete analysis was available for the plagioclase from rock SCxx, alkali and CaO determinations for C2017 and U3027, and careful optical determinations on the others.

Of the eleven rocks from which sanidine phenocrysts were separated

and analyzed, two, SC174 and MN213, are believed to have acquired the sanidine phenocrysts from a foreign source and they will not be further considered. The remaining nine fall into two main groups. The first group contains phenocrysts of sanidine and a plagioclase, near oligoclase-andesine. Two of these, C2017 and Lag1059, have phenocrysts of quartz, biotite and hornblende as well as feldspar. Such rocks make up a large part of the Alboroto quartz latite, and similar rocks are present in the Piedra rhyolite. These rocks have a moderate lime content, and the sanidine phenocrysts are low in soda. The other four rocks of this group have phenocrysts of feldspar and biotite. Such rocks are abundant and widespread in the three rhyolitic divisions of the Potosi volcanic series. These rocks are rather low in lime and the sanidines have a moderate soda content. The second major group contains phenocrysts of quartz, sanidine, and biotite. Rarely they contain a few phenocrysts of albite. Such rocks are absent from the Potosi series, but they make up most of the rhyolite in the Hinsdale formation, the younger rhyolite of the Valles Mountains, New Mexico, the Sunshine Peak rhyolite, and some small intrusive bodies. These rocks are all low in CaO, and the sanidine phenocrysts carry more of the albite molecule than orthoclase. In all three rocks the relative proportions of albite and orthoclase are nearly the same in the sanidine phenocrysts and in the normative feldspar of the rocks in which they are found.

Figure 30 is a plot showing the relation between the CaO content of the rock and the orthoclase content of the sanidine phenocrysts. This curve shows a rather regular decrease in the orthoclase content of the sanidine phenocrysts, with decrease in the total lime content of the rocks in which they occur.

#### SIGNIFICANCE TO PETROGENESIS

In Fig. 29 a curve has been drawn to show the field boundary between sanidine and plagioclase for the lavas of the San Juan region. This curve has a sharp turn at about 5 per cent of anorthite. This break in the curve may be due to the fact that the four points just above the break are for rocks without quartz, while the others have quartz. It may be due to some other complication or to imperfection of the data.

The field boundary between plagioclase and sanidine is of the eutectic type in liquids with over about 5 per cent of anorthite in the normative feldspar, but there is probably a reaction relation between the two feldspars in liquids with less anorthite. This is shown by the fact that in the course of crystallization the sanidines are low in soda in the early stages, become richer in soda as crystallization proceeds, and finally become richer in the albite molecule than the normative feldspar of the



rock in which they occur. A reaction relation between sodic plagioclase and sanidine is also suggested by the fact that the plagioclase phenocrysts of the lavas of the San Juan region rarely become more sodic than calcic oligoclase, and in rocks more alkalic than those that carry such plagioclase, orthoclase forms the only feldspar phenocrysts.<sup>47</sup> Nearly all the rhyolitic rocks of the San Juan region that have plagioclase as the only feldspar fall in the plagioclase field.

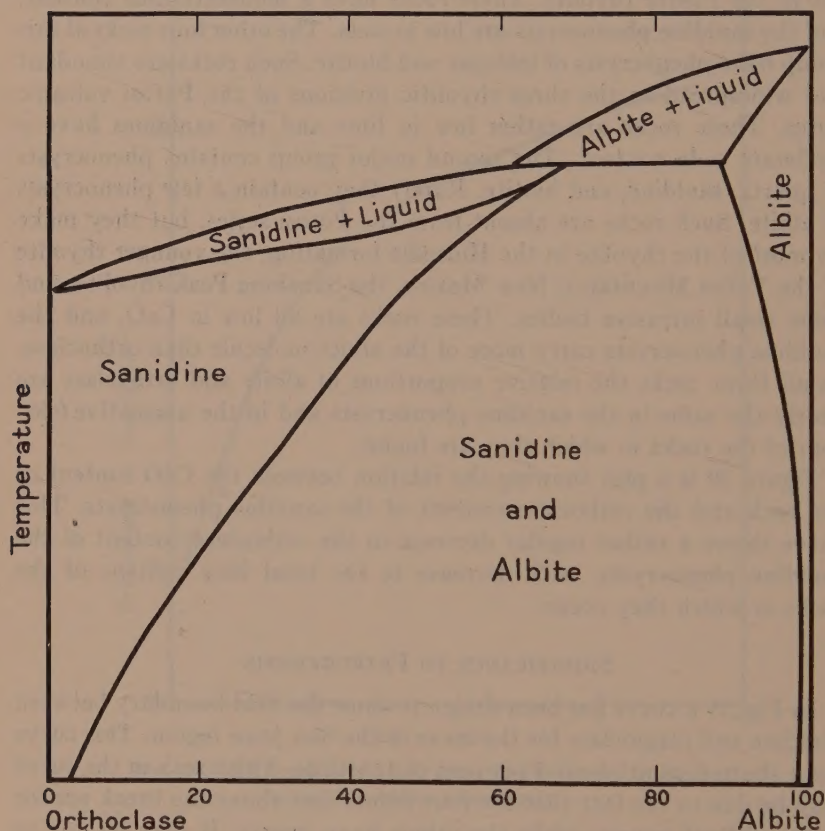


FIG. 31. Curve of crystallization of albite and orthoclase in rocks of the San Juan Mountains.

Figure 31 is a hypothetical curve of crystallization of albite and orthoclase as indicated by the rocks of the San Juan Mountains. This figure is a vertical section through the triangular diagram, orthoclase-albite- $\text{SiO}_2$  + mineralizers and a small amount of other constituents, along the

<sup>47</sup> This Journal, vol. 23, p. 244, 1938.



field boundary between quartz and feldspar. The system would have about 35 per cent of  $\text{SiO}_2$ , some mineralizers, and a small amount of other constituents in addition to orthoclase and albite.

The data in Figs. 29 and 31 can be used to explain the potash-rich rhyolites by a process of fractional crystallization, since the separation of soda-rich sanidine from rocks like those numbered 7 and 9 would enrich the liquid in potash. As the quartz and sanidine phenocrysts appear to be present in approximately the same proportion as they are present in the norm of the rock, the chief change in this process of separating crystals would be to increase the potash content and decrease that of soda. Such potash-rich rocks should be relatively high in silica, and low in lime and the femic constituents. In the variation diagrams of the lavas of the San Juan region and in rocks from other similar provinces, a few of the rocks at the extreme rhyolite end of the diagrams indicate a sharp increase in potash and decrease in soda, without much other change. These are the potash-rich rhyolites. Numerous rock analyses fall on the variation curves just before the change in slope of the curves for the alkalis, but very few fall on the steeper parts of the curves that represent the potash-rich rhyolites. It seems, therefore, that only under exceptional conditions does differentiation proceed to the potash-rich rocks.

#### 9. MINOR ACCESSORIES

ESPER S. LARSEN

In nearly all the basaltic rocks the iron and iron-titanium oxides occur as black magnetite and ilmenite, except in the fragmental and highly vesicular rocks near volcanic vents and in other places where there is evidence of pneumatolytic action. In these red basaltic rocks the mafic minerals are commonly altered. A considerable number of the andesitic rocks, as well as nearly all of the rhyolitic rocks with felsitic groundmass, have the red iron oxide. The rhyolitic glasses, however, have the black iron oxide. In the rhyolites with glassy bases the glassy part has the black oxide, and the red oxide appears abruptly as the groundmass becomes microcrystalline. This abrupt change is well shown where red spherulites are imbedded in black obsidian. The change in the state of oxidation of the iron obviously took place with the crystallization of the groundmass.

Fluorapatite is present in small amount in all the lavas. Zircon is a very minor accessory in the rocks of the area, and it is in unusually small amount, or entirely lacking, in most of the biotite-augite-quartz latites and rhyolites of the Treasure Mountain quartz latite. Even when a heavy liquid and electromagnet concentration of the minerals of these rocks was made, many showed little or no zircon.

Sphene is a common accessory in the rocks. It is nearly as abundant, and in nearly as large phenocrysts, as biotite or hornblende in many of the quartz latites of the Alboroto and Piedra formations. Here sphene is associated with phenocrysts of orthoclase, quartz, plagioclase, biotite, hornblende, and in some cases augite; while it is lacking, or in small amount, in the Treasure Mountain quartz latite, which has about the same chemical composition as the Piedra and Alboroto rocks, but which has phenocrysts of plagioclase, biotite and augite. In general, sphene appears to be more abundant in rocks with hornblende.

Augite and hornblende are present in very small amount in the rhyolites of the area and are found only in a small proportion of the thin sections. However, they are found in small amount—less than 0.1 per cent—in most of the rhyolites, if grains of powdered rock are separated with bromoform and an electromagnet.

#### 10. SUMMARY AND CONCLUSIONS

The volcanic rocks of the San Juan region of Colorado form a great pile that is about 100 miles across and that exceeds 5000 feet in thickness over much of this area. They have been studied in some detail and have been mapped as stratigraphic units. Each unit is composed of many flows and clastic beds. They range in age from Miocene to Quaternary. Long intervals of erosion separate several of the formations. Most of the chemical analyses of the rocks fall near a smooth variation diagram.

The three silica minerals, quartz, tridymite and cristobalite, are abundant in the province and present in nearly equal amounts. Quartz is found as phenocrysts in many of the rhyolitic rocks, as rare foreign grains in a few of the andesites and olivine basalts, and in the groundmasses of some of the lavas, especially in the less siliceous lavas. Tridymite is present in the porous parts of many of the rhyolitic rocks, and in the coarser streaks of the groundmass. It also cements some of the rhyolite tuffs. It is present in the cavities of some of the andesites and basalts. Cristobalite is present as rounded balls perched on the walls of the larger gas cavities of the andesites and basalts, and intergrown with feldspar in the spherulites and dense microfelsitic groundmasses of the rhyolitic rocks. Tridymite crystallized as an unstable form in the presence of abundant mineralizers. Cristobalite also crystallized as an unstable form, either by gas transfer in the larger gas cavities or where crystallization was rapid and not "lubricated" by mineralizers.

Clinopyroxene is the chief mafic mineral in most of the andesites and basalts. It is present with biotite or biotite and hornblende in many of the quartz latites, and it is present in small amount in some of the rhyo-



lites. In the basalts it is interstitial to the feldspar and is of the pigeonite variety. In the other rocks it forms phenocrysts with or without hypersthene and is augite with a moderate iron content.

Hypersthene is rare in rocks with less than 54 per cent of  $\text{SiO}_2$ , it is present in most of the rocks with from 57 to 59 per cent of  $\text{SiO}_2$ , and is uncommon in most rocks with more than 65 per cent of  $\text{SiO}_2$ .

Olivine occurs in rocks with as much as 56 per cent of  $\text{SiO}_2$ , and as much as 12 per cent of normative quartz.

In any rock the ratio  $\text{MgO}/\text{Fe}_2\text{O}_3 + \text{MnO}$  is fairly systematic between the augites and olivines, and it is larger in the olivines than in the augites. In the hypersthene this ratio is less systematic but is commonly nearly the same as in the augites that accompany the hypersthene.

The pyroxene phenocrysts in rocks of about the same chemical composition show considerable variation in iron content, and there is no systematic variation in the iron content of the pyroxenes in rocks that range from pyroxene andesite to rhyolite.

Hornblende is absent from lavas with less than 53 per cent of  $\text{SiO}_2$ , and biotite is rare in rocks with less than 57 per cent of  $\text{SiO}_2$ . Both biotite and hornblende are less abundant in andesites than in latite-andesites, and they are both present in most of the quartz latites. Biotite is commonly the only mafic mineral in the rhyolites except for traces of augite and hornblende. In three formations, each widespread and made up of many flows, the quartz latites have essentially the same range in chemical composition, but the rocks of one formation have phenocrysts of orthoclase, quartz, plagioclase, biotite, hornblende, sphene and augite; those of another lack augite, but otherwise have the same phenocrysts; and those of a third, have phenocrysts of augite, biotite and plagioclase.

The hornblendes vary from green hornblende, in which about two-thirds of the iron is in the ferrous state, to basaltic hornblende in which over 80 per cent of the iron is in the ferric state. The biotites vary from those in which most of the iron is  $\text{FeO}$  ( $\beta=1.63$ ), to those in which the iron is almost entirely  $\text{Fe}_2\text{O}_3$  ( $\beta=1.75$ ). In both the hornblendes and biotites the chief chemical difference between the varieties is in the state of oxidation of the iron.

Resorption of the hornblende and biotite is more extensive in the andesites than in the rhyolites, and it is nearly absent in the glassy rocks. In the early stages of the resorption of these minerals, the pyroxene and iron oxide remain near the original hornblende or biotite crystals; as the process proceeds they are more widely scattered in the groundmass; and finally, in the centers of some of the granular intrusive bodies, all evidence of the original minerals is destroyed and ordinary-looking pyroxene rocks result.

The resorption of hornblende and biotite, and the oxidation of the iron in these minerals, are favored by near-surface conditions. In part these changes took place before the rocks reached the surface, but a large part took place after eruption. Both the resorption of these minerals and the oxidation of their iron are less extensive in the glassy rocks than in the more slowly cooled rocks with crystalline groundmasses. Both these processes are associated with loss of water by the magma, and water may be the oxidizing agent.

The crystallization of biotite and hornblende rather than pyroxene is largely determined by abundance of water in the magma.

In the basalts, plagioclase phenocrysts are very rare and in the silica-rich rhyolites they are absent, or present in very small amount. All the plagioclase phenocrysts have some zoning. In about 10 per cent of the lavas some of the plagioclase phenocrysts have cores that have from 10 to 30 per cent more anorthite than the main outer part, and an equal number of the rocks have plagioclase with cores that have from 10 to 30 per cent less anorthite than the main plagioclase. Both the calcic and sodic cores show extensive resorption and are sharply bounded against the outer zone. About 15 per cent of the rocks have plagioclase phenocrysts of two kinds that differ in anorthite content by from 10 to 30 per cent.

Plots of the anorthite content of the plagioclase phenocrysts against chemical composition of the rocks in which they occur, or against the groundmass or normative plagioclase of the rocks, or the groundmasses in which they occur, show little relation between the plagioclase phenocrysts and the inclosing rocks. In the andesite basalts the plagioclase phenocrysts range from  $An_{20}$  to  $An_{82}$ ; in the quartz latites, near the rhyolites, they range from  $An_{12}$  to  $An_{55}$ . The average plagioclase in the basalts is more calcic than those in the andesites, and they are still less calcic in the average quartz latite.

By using only those rocks that appear from the microscopic study to have plagioclase phenocrysts that crystallized in place, a curve for the course of crystallization of the plagioclase of the lavas in the San Juan region is drawn. It is very different from the curve derived from the melting phenomena of the plagioclase. In many of the rhyolites the plagioclase phenocrysts contain about 25 to 30 per cent of anorthite, and more sodic feldspars are very rare.

Phenocrysts of labradorite contain only one or two per cent of the orthoclase molecule, those of andesine have about 6 per cent, and those of oligoclase-andesine, from 8 to 12 per cent.

The alkalic feldspar phenocrysts are all of the sanidine variety. They are present in very few of the basalts, andesites and andesitic quartz



latites, and where present in such rocks there is good evidence that they are foreign crystals. Sanidine phenocrysts are present in nearly half the rhyolitic quartz latites and in most of the lime-poor rhyolites. In the quartz latites they are invariably associated with oligoclase or sodic andesine and, in some rocks, with quartz. In the rhyolites they are associated with quartz and rare albite.

The anorthite content of the sanidine phenocrysts ranges from  $1\frac{1}{2}$  to  $3\frac{1}{2}$  per cent. The albite content of sanidines from quartz latites, which have about 3.7 per cent of CaO, is 25 per cent. It increases as the lime in the rock decreases, and the sanidine from rhyolites with about a tenth of a per cent of CaO contains 55 to 57 per cent of albite. In the quartz latites the sanidine contains a much larger proportion of potash feldspar than the normative feldspar of the enclosing rock, whereas in the lime-poor rhyolites it contains as much or even more. These data indicate a reaction relation between orthoclase and plagioclase in such rocks, and show that separation of quartz and sanidine from an ordinary rhyolite can form a potash-rich rhyolite.

The indices of refraction of sanidine with 25 per cent of the albite molecule are:  $\alpha=1.522$ ,  $\beta=1.527$ ,  $\gamma=1.527$ ; those for sanidine with 55 per cent of the albite molecule are  $\alpha=1.525$ ,  $\beta=1.530$ ,  $\gamma=1.531$ .

Many of the plagioclase and other phenocrysts of the lavas of the San Juan region did not crystallize from a magma of the composition of the rock in which we find them, but must have been derived from the partial assimilation of other rocks, or by the mixing of two magmas, one or both of which carried crystals. The quartz and sanidine phenocrysts in the andesites and basalts must be foreign. The uniform distribution of the phenocrysts in widespread lava flows, and groups of flows, show that there must have been a thorough mixing of very large masses of magma.

# GARNET CRYSTALS IN CAVITIES IN METAMORPHOSSED TRIASSIC CONGLOMERATE IN YORK COUNTY, PENNSYLVANIA\*

GEORGE W. STOSE AND JEWELL J. GLASS.<sup>1</sup>

## GEOLOGY

Large well-formed crystals of garnet have been found in cavities in metamorphosed Triassic conglomerate in York County, Pennsylvania, 6 miles southeast of Harrisburg. The garnets were formed by contact metamorphism of intrusive diabase. The rounded cavities were produced by the solution of limestone pebbles in the conglomerate, and the calcium of the limestone combined with silica and iron oxide to form garnet. A small amount of hematite is also present in the cavities.

Beds of conglomerate and coarse arkosic sandstone are prevalent in the Heidlersburg member of the Gettysburg shale in the Triassic area southeast of Harrisburg, and make rather high hills on the south side of Susquehanna River from a point one-half mile west of Frogtown to a point 2 miles south of Middletown, where the river turns abruptly south (Fig. 1). The unaltered rock is a gray to buff, granular, pebbly arkose with thin interbedded red shale. Most of the pebbles in the conglomerate are of rounded quartz or quartzite, which weather out and strew the surface of these hills, but occasional pebbles of limestone are generally present. Some layers have such an abundance of limestone pebbles that they have been quarried for lime. The Triassic sedimentary beds in this area strike about N. 80° E. and dip 45° to 60° N.

The sedimentary rocks are intruded by an irregular diabase dike, which cuts sharply across the strike of the sedimentary rocks. From the point 2 miles south of Middletown northwestward for 4 miles the diabase crops out along the south bank of the river, and trends N. 40° W. Its outcrop is here  $\frac{1}{3}$  mile wide. Southwest of Highspire the diabase bends southwestward with the strike, and then continues its northwest trend, and gradually thins to a few hundred feet in width south of New Cumberland. Here it again bends southwestward and widens locally to 1 mile. Northwest of Frogtown it bends sharply southeastward and is more variable in outline, but in general it trends S. 50° E. across the strike of the sedimentary rocks.

The diabase is bordered on both sides by a zone of baked shale and sandstone which varies from  $\frac{1}{8}$  to  $\frac{1}{2}$  mile in width. The metamorphosed

\* Published with the permission of the Director of the United States Geological Survey.

<sup>1</sup> Geology by G. W. Stose, Mineralogy by J. J. Glass.



rock is more resistant than the unaltered sedimentary rock or the diabase, and makes the high ridge south of the diabase. The thicker red shales of the Gettysburg at the diabase contact are baked to hard bluish-black porcelainite with rounded segregations or knots of epidote. The arkose at the contact is silicified and hardened to a tough sandstone or quartzite and is bleached nearly white in places. Limestone pebbles in the arkose are either dissolved by the water accompanying the magma, or are silicified to a gray impure calcareous sandstone.

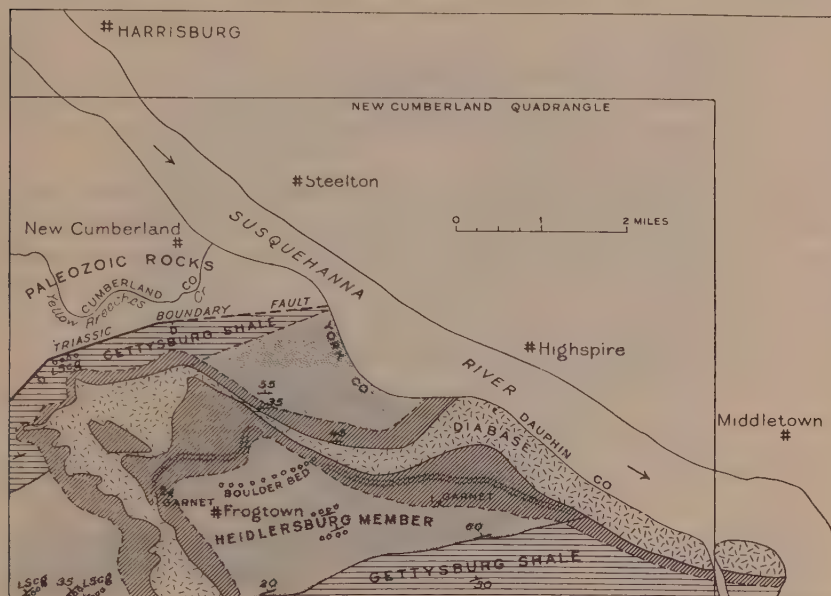


FIG. 1. Geologic map of the area of Triassic rocks southeast of Harrisburg, Pa. Crystals of garnet occur in the metamorphosed zone, shown by diagonal ruling, bordering the intrusive diabase.

The garnet was discovered by G. W. Stose and Malcomb H. Bissell during a geologic survey of the New Cumberland Quadrangle for the Pennsylvania Geological Survey. The best-formed garnets (Fig. 2) were found on the outer edge of the metamorphosed zone which forms the hill south of the diabase, south of Highspire, at the locality marked (1) on Fig. 1. Since its discovery, garnet has been found by Stose and Jonas at many localities to the east and west along the south edge of this metamorphosed zone to a point (locality 2, Fig. 1) on the Lisburn highway,  $\frac{1}{2}$  mile west of Frogtown. Here some of the specimens studied by J. J. Glass were obtained. Many of the solution cavities in these rocks are coated with a thin layer of garnet and hematite. Large well-formed

crystals were obtained only at locality No. 1, two miles south of Highspire.

Magnetite is a general constituent of the diabase in this region, and magnetite-rich solutions evidently accompanied, or followed, the intrusion of the diabase. At Dillsburg and several places to the southwest toward Fairfield, magnetite has replaced limestone in the walls of the intrusive diabase and formed commercial deposits of iron ore. These magnetite deposits occur adjacent to thick cross-cutting bodies of diabase believed<sup>2</sup> to be at, or near, the vents in the floor of the Triassic basin up which the magma ascended, and therefore, are closely connected with its source. These magnetite-rich solutions evidently also were the source of the iron that combined to form the andradite garnet at the contact of limestone with the intrusive diabase 2 to 3 miles north of Fairfield.

Garnet (probably andradite) associated with pyroxene, pyrite, and magnetite, is described by Harder<sup>3</sup> as occurring in the baked Triassic sandstone and shale in the magnetite mines at Dillsburg. Shannon<sup>4</sup> describes minute crystals of a lime-iron garnet (andradite) associated with magnetite and as slickenside coatings in fissures in limestone altered by diabase at Leesburg, Virginia.

## MINERALOGY

### PROPERTIES OF THE ANDRADITE GARNETS

The garnets referred to above are the calcium-iron variety, andradite, and show the following properties:

*Physical properties.*—The garnet crystals in the rounded cavities (Fig' 2), from 2 miles south of Highspire, vary in size from 1 centimeter to nearly 2 centimeters in diameter. The upper three-quarters of each crystal is bounded by trapezohedral faces, and shows the  $n(211)$  simple form. The trapezohedral faces are all conspicuously striated. The striae are parallel to the longer diagonals on those faces whose edges are so joined that four corners form a point, and are parallel to the short diagonal on the other faces. The sides of the crystals attached to the walls of the cavity are flattened and show a series of striated divisions into segments that form angles resembling elbow-twinning patterns. No cleavage is observed, and none of the crystals show a tendency to separate along the bands of zoning nor along the individual segments or

<sup>2</sup> Stose, G. W., Fairfield-Gettysburg Folio, Pa.: *U. S. Geol. Surv.*, Folio 225, p. 19, 1929.

<sup>3</sup> Harder, E. C., Structure and origin of the magnetite deposits near Dillsburg, York Co., Pa.: *Econ. Geol.*, vol. 1, p. 619, 1910.

<sup>4</sup> Shannon, E. V., Mineralogy and petrography of Triassic limestone conglomerate metamorphosed by intrusive diabase at Leesburg, Va.: *Proc. U. S. Natl. Mus.*, vol. 66, Art. 28, pp. 10–11, 1925.



twinning units. The specific gravity is 3.6. Hardness between 6 and 7. Luster resinous. Fuses to a black magnetic bead. The color of the crystals in mass is nearly black, but on thin edges is yellow to reddish brown.

*Optical properties.*—A thin section of one of these garnets examined under crossed nicols showed a sharply defined doubly refracting zone consisting of parallel bands or lamellae with varying faint extinction. The birefracting areas form the outer zone of the crystal and surround

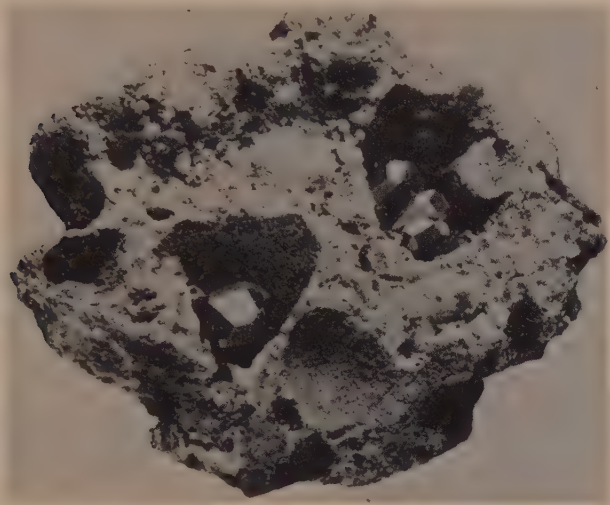


FIG. 2. Crystals of andradite garnet in cavities in metamorphosed Triassic conglomerate, 2 miles southwest of Highspire, Pa.

a completely isotropic central area, similar to the Fairfield garnet shown in Fig. 3. It has been noted in previous studies of andradite garnet that the crystals are often composed of parts which are anisotropic, together with others which are isotropic, in which the isometric form is said to be retained by twinning, the twinning units being pyramids whose vertices meet at the center and whose bases are the external faces of the isometric form. The garnets from 2 miles south of Highspire, however, do not consist of pyramids whose vertices meet at the center, but their twinning units form a border inclosing a central completely isotropic area that has a slightly higher index of refraction than does the border zone. The birefracting areas of the garnets from 2 miles south of Highspire are much less conspicuous than those from near Fairfield, described farther on. The contacts of the banded segments are not so sharply defined, and the segments do not assume the regular

pattern arrangement that is characteristic of the Fairfield garnets shown in Fig. 3. There is no apparent zone of weakness, that is, a tendency for parting, at the boundary between the isotropic area and the anisotropic area as is frequently observed in the case of interrupted crystal growth.

In thin section the color is pale yellow to yellowish amber; in thicker grains the yellow shows a greenish tinge. In the doubly refracting areas the positive acute bisectrix is normal to the twinning lamellae; the optic plane is normal to the length of the broad birefracting bands next to the central area. The index of refraction for the isotropic areas is:  $n=1.886$ ,

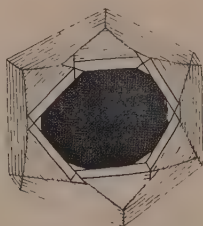


FIG. 3. Sketch of a thin section of andradite crystal ( $\times 16$ ) which exhibits striking optical anomalies. The crystal is one of an aggregate of garnets found in contact rock 2 to 3 miles north of Fairfield, Pennsylvania. The central area of the crystal is completely isotropic, represented by the dark center in the diagram; the adjoining areas are anisotropic and are represented by the broad white bands and white triangles; and the outer zone is composed of narrow thread-like bands, alternating isotropic and anisotropic, resembling the lamellar twinning of plagioclase, and is represented by the ruling. The individual segments consist of adjoining outward and inward pointing triangles arranged in a nearly symmetrical hexagonal pattern.

and for the doubly refracting area is slightly lower,  $n=1.865$ ,  $B$ =about .003. Garnet crystals collected  $\frac{1}{2}$  mile west of Frogtown, in the same geologic relations, are identical with those from south of Highspire. Small crystals (1.5 mm.) of a yellow-green garnet associated with calcite and magnetite, collected at Grantham, also have the same optical properties as those from Highspire.

The garnet from near Fairfield occurs as a mass of small crystals of a coarse granular type of andradite, brownish yellow to dark reddish brown in color and resinous in luster (colophonite, named after the resin colophony). The trapezohedral faces persist in these garnets, each tiny individual crystal exhibiting the same external features as are seen on the larger crystals in the cavities south of Highspire. The optical properties, however, are slightly different. The anisotropic areas are distinctly banded, and the opposite segments extinguish evenly. The optical axial angle is small, in some crystals sensibly uniaxial. The sign is positive, and the indices of refraction are variable, from 1.870 to 1.850. Each small crystal is apparently homogeneous in composition,

but the different crystals vary slightly from one another in index of refraction. This indicates a variation in composition from andradite, principally of the calcium-iron molecule, to andradite with a little of the calcium-aluminum molecule, grossularite.

A thin section of the contact rock at Fairfield, which is almost a solid mass of small garnet crystals, shows numerous examples of optical anomalies. The cross section of a typical andradite crystal from this contact rock is shown in Fig. 3. The crystals show segmented concentric structures composed of symmetrical triangular areas whose individual segments are made up of narrow alternate isotropic and anisotropic bands, which produce a lamellar twinning effect. This banded zone surrounds a completely isotropic central area. In transmitted light there is no distinguishable difference between the isotropic and anisotropic areas, neither in color nor in index of refraction. Under crossed nicols the two segments on opposite sides of the isotropic center extinguish simultaneously.

Experimental work by Merwin<sup>5</sup> at the Geophysical Laboratory of the Carnegie Institution, Washington, D.C., shows that birefringent types of garnets invert at about 800°C. to a strictly isotropic form. His experimental data indicate that the temperature of the environment in which these andradite garnets formed was lower than 800°C.

A similar experiment was performed by one of the authors (J. J. Glass) in the laboratory of Dr. Charles P. Saylor, at the U. S. Bureau of Standards, on a sample of the anisotropic andradite from York County, Pa. At 860°C. the anisotropic grains became isotropic, and did not invert on cooling down. The results of this experiment furnish some additional confirmatory evidence to support the work of Merwin, and indicates that a temperature factor is involved in the anisotropism of andradite, which may serve as a geological indicator.

<sup>5</sup> Merwin, H. E., *U. S. Geol. Survey, Professional Paper* 87, p. 108, 1915.



# THE COMPOSITION AND OCCURRENCE OF GARNETS\*

W. I. WRIGHT, *University of Minnesota,  
Minneapolis, Minnesota.*

## INTRODUCTION

During the last seventy-five years several hundred chemical analyses of garnets have been made by chemists and mineralogists throughout the world. This paper is an effort to collect and arrange all these analyses in order to show which particular garnet is characteristic of each rock type.

Two new chemical analyses of garnets from mica schists were made by the writer; one from Amisk Lake, Saskatchewan, and a second from Alaska.

In addition the writer estimated the composition of 23 garnets from various rock types by determining in each case the index of refraction, specific gravity, and the quantitative amount of ferrous iron. A qualitative test was also made for manganese.

## ESTIMATION OF THE CHEMICAL COMPOSITION OF GARNETS BY PHYSICAL AND CHEMICAL METHODS

Studies by Ford,<sup>1</sup> Stockwell<sup>2</sup> and Fleischer<sup>3</sup> on the relation between physical properties and chemical composition of garnets show that a very close connection exists between index of refraction, specific gravity, x-ray pattern and chemical composition. Ford demonstrated from his study that if the index of refraction, specific gravity, and various tests for the chief components are made, it is nearly always possible to determine fairly closely the chemical composition of the garnet.

Table 1 gives the index of refraction, specific gravity, ferrous iron content and the presence, or absence, of manganese of the garnets listed. From these data the proportions of the various molecules present in garnet can be estimated. These compositions are plotted in Figs. 1 to 8.

Table 2 records the chemical analyses made by the writer of two garnets obtained from mica schists.

\* Abstract of a thesis submitted in partial fulfillment for the degree of Doctor of Philosophy, University of Minnesota, Minneapolis, Minnesota.

<sup>1</sup> Ford, W. E., A study of the relations existing between the chemical, optical and other properties of the garnet group: *Am. Jour. Sci.*, 4th. Series, pp. 33-49, 1915.

<sup>2</sup> Stockwell, C. H., *Am. Mineral.*, vol. 12, p. 327, 1927.

<sup>3</sup> Fleischer, M., *Am. Mineral.*, vol. 12, p. 751, 1937.

TABLE 1. COMPOSITION OF GARNETS FROM VARIOUS ROCK TYPES

No.	Index	Specific Gravity	% FeO	Mn. Present or Absent	Estimated Composition				
					Sp	Gr	Py	Al	An
1.	1.795	4.08	31.4	Present	10		8	72	10
2.	1.803	4.20		Present	70	5	5	20	
3.	1.802	4.09	32.0	Present	5	6	15	74	
4.	1.795	4.02	31.9	Present	4	10	15	71	
5.	1.805	3.97	29.1	Trace	2	5	15	68	10
6.	1.775	3.90	17.8	Absent		35	15	46	4
7.	1.779	3.92	20.7	Absent		16	35	49	
8.	1.792	4.00	31.6	Absent		10	10	73	7
9.	1.802		27.5	Present	6	15	15	64	
10.	1.798	4.00	29.3	Present	3	5	15	67	10
11.	1.809	4.10	33.6	Present	6	5	10	79	
12.	1.873			Absent		10		5	85
13.	1.783	3.88	21.9	Absent		20	30	50	
14.	1.739			Absent		25	55	20	
15.	1.888	3.78		Absent		5	5		90
16.	1.808			Absent		60	5	5	30
17.	1.736			Absent		85	10		5
18.	1.866	3.75		Absent		10		10	80
19.	1.804			Absent		50	5	5	40
20.	1.809			Absent		45	5	10	40
21.	1.804			Absent		50	5	5	40
22.	1.783	3.99	26.0	Absent		30	5	60	5
23.	1.887	3.81		Absent		5		5	90

Sp=Spessartite

Gr=Grossularite

Py=Pyrope

Al=Almandite

An=Andradite

## DESCRIPTION AND LOCATION OF ROCKS FROM WHICH GARNETS OF TABLE 1 WERE TAKEN.

1. A few grains of garnet found in clusters in biotite in a pegmatitic granite boulder from Jellicoe, Ontario.
2. Garnet enclosed in muscovite flakes of pegmatite from Connecticut.
3. Garnetiferous gneiss from New Hampshire.
4. Garnet-biotite gneiss from Sturgeon River, Saskatchewan.
5. Garnet-andalusite schist from Amisk Lake, Saskatchewan.
6. Sillimanite-garnet gneiss from Burgess, Ontario.
7. Garnet-biotite-hornblende schist from Markstay, Ontario.
8. Light gray sedimentary gneiss from Lake Harbour, Baffin Land.
9. Chlorite schist from Minnesota, Sec. 16, T 27, NR, 67 W.
10. Garnet crystal in biotite schist from Western Ontario.
11. Garnet crystal in biotite schist from Connecticut.
12. Garnet in greenstone from Minnesota.
13. Garnet from anorthosite boulder, Adirondacks, New York.
14. Garnet from eclogite, Bavaria.

15. Garnet from iron formation, East Mesabi, Minnesota.
16. Garnet from aplite dolomite contact, Potgietersrust, Bushveld, South Africa.
17. Garnet from limestone, Ariege.
18. Garnet from limestone, Broadway mine, south end of Boulder Batholith, Montana.
19. Garnet from limestone, Bannack, Montana.
20. Garnet from limestone, Puy de Pegnires, Hautes Pyrenees.
21. Garnet from limestone, Bannack, Montana.
22. Garnet from limestone, Franklin, North Carolina.
23. Garnet from limestone, Pass between Tincup and Pitkin, Colorado.

TABLE 2. CHEMICAL ANALYSES OF TWO GARNETS FROM BIOTITE SCHISTS

## Number 1. From Amisk Lake, Northern Saskatchewan.

	%	Mol.	Per cent molecules by weight	
SiO <sub>2</sub> .....	36.00	613	Spessartite	4.6
Al <sub>2</sub> O <sub>3</sub> .....	22.61	221	Grossularite	6.5
Fe <sub>2</sub> O <sub>3</sub> .....	2.67	016	Pyrope	7.4
FeO.....	32.12	446	Almandite	81.5
MgO.....	2.19	054		
CaO.....	2.36	042		
MnO.....	1.86	025		
Total	100.01			

## Number 2. From Alaska.

	%	Mol.		
SiO <sub>2</sub> .....	39.86	664		
Al <sub>2</sub> O <sub>3</sub> .....	21.76	213		
Fe <sub>2</sub> O <sub>3</sub> .....	.68	004	Spessartite	3.7
FeO.....	29.98	416	Grossularite	4.8
MgO.....	4.63	115	Pyrope	16.4
CaO.....	1.66	029	Almandite	75.1
MnO.....	1.44	020		
Total	100.61			

## METHOD EMPLOYED IN COLLECTING AND PRESENTING ANALYSES

The literature was searched for analyses of garnets which were accompanied by petrographic descriptions of the rocks or mineral associations from which they were taken. Many were rejected because there was no report on the character of the rock. All analyses were discarded that contained considerable amounts of elements that are unusual to the garnet molecule. The study was confined to the five common members of the garnet group, namely: spessartite, grossularite, pyrope, almandite and andradite. The compositions are expressed by weight of the garnet molecule and calculated to one hundred per cent. They are tabulated in Table 3.



TABLE 3

No.	Sp	Gr	Py	Al	An	No.	Sp	Gr	Py	Al	An
1.	50.5		2.8	46.7		47.			17.2	79.8	3.0
2.	89.1	3.0	4.6	3.3		48.	5.3		.9	91.4	2.4
3.	59.8			37.2	3.0	49.	17.3		7.0	71.4	4.3
4.	88.5	1.8		9.7		50.	20.7		6.8	68.5	4.0
5.	41.0	2.5	1.7	50.0	4.8	51.	9.0	6.8	4.4	80.8	
6.	59.9	1.3	2.8	36.0		52.	55.7			40.9	3.4
7.	68.5	.8	.5	30.2		53.	10.8		13.0	73.0	3.2
8.	37.3		4.5	46.3	11.9	54.	65.5	1.9		31.5	1.1
9.	42.0		1.0	53.3	3.7	55.	58.0	4.0		38.0	
10.	84.1			15.9		56.	10.1		11.7	73.8	4.4
11.	62.8	11.7	4.6	18.2	2.7	57.	34.9	17.5		38.2	9.4
12.	33.0		3.4	63.6		58.	45.9		7.3	35.5	11.3
13.	77.4			16.0	6.6	59.	34.8	4.5	5.7	55.0	
14.	79.9	3.1		17.0		60.	17.0			83.0	
15.	21.0	4.3	4.7	70.0		61.	7.3		3.6	84.6	
16.	16.0	7.9	4.1	72.0		62.	16.4		3.3	74.6	5.7
17.	21.2	4.8	5.3	67.7		63.	48.9	12.7	10.2	28.2	
18.	33.9	7.0		59.1		64.	58.5	1.9	2.8	36.8	
19.	51.8	4.7	6.7	36.8		65.	46.4	5.7		47.9	
20.	2.7		26.5	70.8		66.	15.6	5.8	16.0	62.6	
21.	32.5	5.8		54.3	7.4	67.	10.5		4.5	81.0	
22.	11.8	2.8	12.0	73.4		68.	50.5			49.5	
23.	20.0	2.0	4.5	73.5		69.	13.3	3.2	6.0	77.5	
24.	31.2	8.9		59.9		70.	12.4		9.5	70.7	7.4
25.	89.5			8.0	2.5	71.	7.1			88.3	4.6
26.	51.9	4.7	6.9	36.6		72.	18.0	8.0	16.0	58.0	
27.	54.0		6.5	34.5	5.0	73.	7.7	6.0	16.3	70.0	
28.	4.4		16.6	74.1	4.9	74.	5.0	5.9	16.9	65.0	7.2
29.	1.4	15.7	29.0	53.9		75.			29.1	67.0	3.9
30.	61.3	2.6	.5	35.6		76.	3.0	9.8	16.2	71.0	
31.	11.8		11.8	73.5	2.9	77.	7.8	10.9	6.7	67.1	7.5
32.	68.2	8.0		23.8		78.		4.8	7.8	87.4	
33.	90.0	4.8	.8	4.4		79.		6.3	7.0	86.7	
34.	45.1	4.0		50.9		80.	2.7	4.1	12.4	80.8	
35.	39.8	2.5		57.7		81.	3.2	5.8	8.6	82.4	
36.	21.7	2.6		75.7		82.	3.6	5.6	16.8	74.0	
37.	66.9	.5		32.6		83.	2.2	3.8	14.7	78.3	1.0
38.	33.7	1.9	2.9	60.5		84.	2.3	2.8	20.3	74.6	
39.	34.8			65.2		85.	1.6	1.8	25.2	71.4	
40.	36.8	2.9	3.3	57.0		86.	4.9	4.6	17.1	73.4	
41.	67.5			32.5		87.	2.2	11.1	5.8	80.9	
42.	52.0	6.4		41.6		88.			10.2	76.3	13.5
43.	78.4	1.5	1.0	19.1		89.		2.6	10.9	86.5	
44.	71.0			20.0		90.	18.0	8.0	16.0	58.0	
45.	64.0	1.0		31.0	4.0	91.	1.8	8.8	.6	72.2	16.6
46.	4.8	4.0	11.3	79.9		92.	.9		27.5	65.5	6.1

TABLE 3 (Continued)

No.	Sp	Gr	Py	Al	An	No.	Sp	Gr	Py	Al	An
93.	4.9	8.6	8.5	78.0		141.		33.0	36.0	31.0	
94.	8.8	10.6	7.8	74.8		142.		33.0	49.0	18.0	
95.		19.8	23.0	57.2		143.		17.4	48.6	34.0	
96.	16.1		4.0	71.8	8.1	144.		12.7	63.2	24.1	
97.	2.0	9.2		88.8		145.		13.3	51.5	25.2	
98.	1.7	18.2	13.4	66.7		146.		11.5	66.9	21.6	
99.	2.0	31.0	17.3	49.7		147.			67.2	19.8	13.0
100.		29.7	14.5	54.8		148.			65.7	19.4	14.9
101.	6.5	17.2	12.9	63.4		149.		13.6	67.3	19.1	
102.		28.3	12.7	59.0		150.			64.7	17.7	17.6
103.		15.7	38.0	46.3		151.	2.0		64.6	16.8	16.6
104.	12.5	8.0	10.6	47.0	21.9	152.	1.0	16.0	83.0		
105.	8.9	9.4	13.4	59.0	10.3	153.	.4		76.6	15.1	7.9
106.	1.4	10.6	48.0	39.4		154.		12.5	87.5		
107.	3.7	13.9	29.6	53.0		155.		14.8	85.2		
108.	1.0	5.1	38.3	55.6		156.		10.0	81.9		8.1
109.	2.0	17.5	36.6	43.9		157.		13.3	85.4		1.3
110.	1.2	36.6	49.2	13.4		158.		13.0	87.0		
111.	2.0	12.0	25.0	61.0		159.	.9	5.2	71.6	14.7	7.6
112.	4.4	16.0	15.0	65.0		160.		81.0	10.0		9.0
113.	1.5	30.0	8.5	60.0		161.		95.3	1.8	1.2	1.7
114.		19.0	20.0	51.0	10.0	162.	1.5	6.7	28.0	55.8	8.0
115.	12.0	22.0	19.0	47.0		163.	3.0	13.7	24.3	59.0	
116.		21.0	16.0	48.0	15.0	164.	1.1	85.3	1.3	1.1	11.2
117.		29.1	27.7	43.2		165.	1.5	84.0			14.5
118.			74.9	18.7	6.4	166.	3.9	5.3	9.6	81.2	
119.			56.3	43.7		167.	.5			.7	98.8
120.			62.9	23.0	14.1	168.		18.2	39.6	42.2	
121.			51.1	34.2	14.7	169.		18.0	53.0	29.0	
122.		5.7	33.4	46.5	14.4	170.		18.0	50.0	32.0	
123.		11.4	60.4	28.2		171.		18.0	50.0	32.0	
124.	2.4	30.0	16.8	50.8		172.		22.0	40.0	38.0	
125.		13.8	37.6	48.6		173.		18.0	44.0	38.0	
126.		23.5	13.3	63.2		174.			30.8	48.8	30.4
127.		21.5	43.4	35.1		175.		29.2		7.6	63.2
128.		19.0	37.7	43.3		176.		85.9	6.9		7.2
129.		21.1	44.4	34.5		177.		19.1		1.0	79.9
130.		26.6	30.3	43.1		178.		24.5		.6	74.9
131.		20.5	14.4	65.1		179.		19.7		1.9	78.4
132.		12.4	30.9	56.7		180.		94.3			5.7
133.	2.6	41.4	20.7	35.3		181.		93.5	.5		6.0
134.		12.6	81.5	5.6		182.		60.3	1.8	1.7	36.2
135.	2.0	9.0	34.5	34.0	20.5	183.		44.4	1.3	3.1	51.2
136.	2.3	31.8	19.1	46.8		184.		84.0	4.0		12.0
137.	.5	36.0	50.9	12.6		185.	1.5	27.9		8.0	62.6
138.	8.0	20.7	48.0	8.0		186.				11.3	88.7
139.		30.0	10.0	56.0	4.0	187.				5.0	95.0
140.	1.0	6.0	17.8	63.8	11.9	188.		84.4		3.6	12.0

TABLE 3 (Continued)

No.	Sp	Gr	Py	Al	An	No.	Sp	Gr	Py	Al	An
189.	1.8	26.3		6.1	65.8	207.		98.4	1.4		
190.		23.7	12.7	63.3		208.	.8	72.2	6.7	20.1	
191.		3.9		9.0	87.1	209.	3.5	54.5		8.0	34.0
192.	.2	85.0	1.1	.5	13.2	210.					100.0
193.		83.5	2.4		14.1	211.		39.5			60.5
194.				3.4	96.6	212.		65.2			34.8
195.	.7	63.4	1.0	1.7	33.2	213.		38.6			61.4
196.	2.1	91.7	2.1		4.1	214.		35.7			64.3
197.		97.2	2.8			215.	1.4	63.4		9.9	25.3
198.	.9	88.7	2.3	8.1		216.	.5	57.8		4.2	37.5
199.	1.5	59.0		39.5		217.	.5	84.3			15.2
200.	1.0	8.8	.6	72.8	16.8	218.					100.0
201.		29.8	7.3		62.9	219.			5.7		94.3
202.	1.5	72.9	6.0		19.6	220.		92.5			7.5
203.		99.2	.8			221.	1.4	77.4	1.4		19.8
204.	1.0	44.3	4.2	.5	50.0	222.	1.0	30.5		4.5	64.0
205.		46.2			53.8	223.		70.8			29.2
206.	3.2	96.8									

## INDEX TO TABLE 3

Numbers 1- 35, garnets from pegmatites.

Numbers 36- 53, garnets from granites.

Numbers 54- 73, garnets found associated with contact action on siliceous rocks.

Numbers 74- 96, garnets from biotite schists.

Numbers 97-116, garnets from amphibole schists.

Numbers 117-147, garnets from eclogites.

Numbers 148-159, garnets from kimberlites and peridotites.

Numbers 160-174, garnets from other basic rocks; such as gabbro, anorthosite and basalt.

Numbers 174-223, garnets from calcareous contact rocks.

## SUMMARY OF TABLES

The average proportion of the major molecules of garnets in the rock types are:

Rock Type	Spessartite	Grossularite	Pyrope	Almandite	Andradite
Pegmatite	47.1			41.8	
Granite	36.0			56.8	
Garnets associated with contact action on siliceous rocks	30.7			56.4	
Biotite schists		6.0	13.8	73.0	
Amphibole schists		20.7	20.3	53.6	
Eclogites		18.5	37.4	39.1	
Kimberlites and peridotites		9.0	72.3	13.4	
Various basic rocks		28.7	20.7	34.4	15.6
Calcareous contact rocks		51.5			40.8



## SOURCES OF ANALYSES IN TABLE 3

- 1- 3. *Soc. franc. Mineral.*, vol. 37, p. 108, 1914.
4. *Am. Mineral.*, vol. 13, p. 463, 1928.
- 5- 7. *Neues Jahrb. Mineral.*, Referate 1, p. 532, 1930.
8. Hintze, *Handbuch der Mineral.*, vol. 2, p. 77, No. 1.
9. *Am. Mineral.*, vol. 20, p. 19, 1935.
10. *Neues Jahrb. Mineral.* Referate 1, p. 445, 1929.
11. *Geol. Survey India*, vol. 68, Part 3, p. 340, 1934.
12. *Am. Mineral.*, vol. 7, p. 171, 1932.
13. *Neues Jahrb. Mineral.*, Referate 1, p. 140, 1920.
14. *Neues Jahrb. Mineral.*, Referate 1, p. 218, 1926.
- 15- 17. *Neues Jahrb. Mineral.*, Referate 1, p. 249, 1929.
18. *Zeits. Krist.*, vol. 45, p. 317, 1908.
19. *Zeits. Krist.*, vol. 57, p. 229, 1922.
20. *Zeits. Krist.*, vol. 35, p. 319, 1902.
21. *Centralb. Mineral.*, Part A, p. 245, 1927.
22. *Centralb. Mineral.*, Part A, p. 253, 1927.
23. *Centralb. Mineral.*, Part A, p. 5, 1932.
24. *Geol. Survey India*, vol. 68, Part 3, p. 346, 1934.
25. *U.S.G.S., Bull.* 60, p. 129, 1890.
26. *Neues Jahrb. Mineral.*, Referate, Part 1, p. 279, 1917.
- 27- 31. *Neues Jahrb. Mineral.*, Beil. Band 55, Abt. A, p. 64, 1927. Nos. 35, 36, 38, 39, 48.
32. *Zeits. Krist.*, vol. 22, p. 310, 1894.
33. *Am. Mineral.*, vol. 17, p. 17, 1932.
- 34- 35. *Geol. Soc. London, Q.J.*, Part 3, p. 343, 1934.
- 36- 42. Hintze, *Handbuch der Mineral.*, vol. 2, p. 70. Nos. 1, 19, 10, 13, 16, 17, 15.
- 43- 46. *Neues Jahrb. Mineral.*, Beil. Band 55, Abt. A, p. 64, 1927. Nos. 54, 30, 37, 48.
47. *Zeits. Krist.*, vol. 70, p. 265, 1929.
48. *Geol. Soc., London, Q.J.*, vol. MC, Part 3, p. 343, 1934.
49. *Geol. Soc., London, Q.J.*, p. 189, May 1932.
- 50- 51. *Mineral. Mag.*, vol. 24, p. 254, March 1936.
- 52- 53. *Neues Jahrb. Mineral.*, Referate 2, p. 169, 1931.
54. *Am. Jour. Sci.*, vol. 31, p. 435, 1886.
55. *Mineral Mag.*, Abstracts, vol. 4, No. 11, p. 517, 1931.
56. *Mineral. Mag.*, (No. 81), p. 210, September 1915.
57. *Mineral. Mag.*, vol. 2 (No. 10), p. 473, 1925.
- 58- 60. *Mineral. Mag.*, vol. 21 (No. 113), p. 47, 1926.
- 61- 62. *Neues Jahrb. Mineral.*, Referate 2, p. 535, 1930.
- 63- 64. *Bull. Soc. franc. Mineral.*, vol. 51, pp. 275-84, 1928.
65. *Gt. Brit. Geol. Survey*, Analyses of Igneous Rocks and Minerals, p. 147, 1931.
- 66- 67. *Neues Jahrb. Mineral.*, Beil. Band 34, p. 94, 1912.
68. *Journ. Royal Soc. Western Australia*, vol. 14, pp. 45-56, 1928.
69. *Zeits. Krist.*, vol. 33, p. 658, 1900.
70. *Zeits. Krist.*, vol. 57, p. 228, 1922.
71. *Zeits. Krist.*, vol. 23, p. 292, 1894.
72. *Neues Jahrb. Mineral.*, Beil. Band 55, Abt. A, p. 64, 1927.
73. *Royal Soc. Western Australia*, vol. 18, pp. 61-74, 1931-32.
- 74- 75. *Royal Soc. Canada*, vol. 24, Section IV, p. 123, 1930.
- 76- 77. Unpublished, Analyses made at University of Toronto.

- 78-79. *Bull. Am. Geol. Soc.*, vol. **47**, p. 786, 1936.
80. *Am. Jour. Sci.*, vol. **32**, p. 310, 1896.
81. *Econ. Geol.*, vol. **30**, p. 393, 1935.
82. *Zeits. Krist.*, vol. **22**, p. 310, 1894.
83. *Centralb. Mineral.*, p. 656, 1924.
- 84-85. *Neues Jahrb. Mineral.*, Beil. Band **34**, p. 136, 1912.
86. *Neues Jahrb. Mineral.*, Referate 2, p. 39, 1922.
- 87-88. *Zeits. Krist.*, vol. **57**, p. 228, 1922.
89. *Zeits. Krist.*, vol. **7**, p. 111, 1883.
- 89-91. *Neues Jahrb. Mineral.*, Beil. Band **55**, Abt. A, p. 63, 1927. Nos. 18, 51, 4.
92. *Zeits. Krist.*, vol. **2**, p. 104, 1878.
93. *Zeits. Krist.*, vol. **8**, p. 503, 1897.
- 94-95. *Zeits. Krist.*, vol. **33**, p. 655, 1900.
96. *Zeits. Krist.*, vol. **57**, p. 228, 1922.
97. *Mineral. Mag.*, vol. **21** (No. 113), p. 86, 1926.
98. *Tschermak's Min. und Pet.*, vol. **36**, p. 9, 1923-25.
99. *Centralb. Mineral.*, Part A, p. 316, 1927.
100. *Neues Jahrb. Mineral.*, Referate 2, p. 399, 1932.
101. *Mineral. Mag.*, vol. **22** (No. 129), p. 255, 1930.
102. *Tschermak's Min. und Pet.*, vol. **43**, p. 87, 1933.
103. *Zeits. Krist.*, vol. **36**, p. 421, 1902.
- 104-105. *Geol. Soc. London, Q.J.*, vol. **90**, p. 388, 1934.
- 106-110. *Soc. franc. Mineral.*, vol. **37**, p. 112, 1914.
- 111-113. *Skriffer Ungivine Af Videnskaps-Selskaht, Kristiania*, vol. **1**, p. 110, 1921.
- 114-116. *Am. Mineral.*, vol. **16**, p. 329, 1931.
- 117-121. Williams, A. E., *Genesis of the Diamond*, vol. **2**, p. 376.
- 122-127. Williams, A. E., *Genesis of the Diamond*, vol. **1**, p. 351.
128. Analyses of Rocks and Minerals, *Gt. Brit. Geol. Survey*, p. 176, 1931.
129. *Mineral. Mag.*, vol. **24**, p. 425, 1936.
- 130-131. *Bull. Soc. franc. Mineral.*, vol. **43**, p. 98, 1920.
- 132-137. *Neues Jahrb. Mineral.*, Beil. Band **55**, Abt. A, pp. 63-64, 1927. Analyses No. 14, 6, 29, 15, 52, 24.
- 138-139. *Am. Mineral.*, vol. **16**, p. 330, 1931.
- 140-142. Escola, P., *Videnskapsskel, Skrifter, I, Mau- naturv. Kl., Kristiania*, vol. **1**, p. 44, No. 8, 1921.
- 143-150. Williams, A. E. *Genesis of the Diamond*, vol. **2**, p. 376.
151. *Neues Jahrb. Mineral.*, Referate 2, p. 169, 1931.
- 152-159. *Neues Jahrb. Mineral.*, Beil. Band **55**, Abt. A, p. 64, 1927.
160. *Zeits. Krist.*, vol. **17**, p. 307, 1890.
161. *Neues Jahrb. Mineral.*, Referate, Band **1**, Abt. A, p. 137, 1926.
- 162-163. Escola, P., *Skriffer Ungivine Af Videnskaps-Selskabet Kristiania*, vol. **1**, pp. 89 and 113, 1921.
164. *Zeits. Krist.*, vol. **57**, p. 230, 1922.
165. *Trans. Royal Soc., Edinburgh*, vol. **51**, p. 8, 1915.
166. *Zeits. Krist.*, vol. **45**, p. 317, 1908.
167. *Journ. Royal Soc., Western Australia*, vol. **14**, p. 53, 1927-28.
- 168-174. *Skriffer Ungivine Af Videnskaps-Selskabey, Christiania*, vol. **1**, p. 90, 84, 100, 1921.
175. *Zeits. Krist.*, vol. **57**, p. 230, 1922.
176. *Zeits. Krist.*, vol. **35**, p. 300, 1902.
177. *Zeits. Krist.*, vol. **48**, p. 119, 1911.

178. *Zeits. Krist.*, vol. **70**, p. 266, 1929.
179. *Zeits. Krist.*, vol. **52**, p. 314, 1913.
180. *Zeits. Krist.*, vol. **22**, p. 293, 1894.
181. *Zeits. Krist.*, vol. **10**, p. 313, 1883.
- 182-183. *Zeits. Krist.*, vol. **46**, p. 389, 1909.
184. *Zeits. Krist.*, vol. **21**, p. 155, 1892.
185. *Zeits. Krist.*, vol. **57**, p. 229, 1922.
186. *Zeits. Krist.*, vol. **36**, p. 519, 1902.
187. *U.S.G.S. Professional Paper*, vol. **42**, p. 134, 1905.
188. *Am. Jour. Sci.*, vol. **24**, 5th. Series, p. 77, 1932.
189. *Bull. Comm. Geol. Finland*, No. **40**, p. 231, 1914.
190. *Centralb. Mineral.*, Part A, p. 237, 1933.
- 192-193. *Am. Mineral.*, vol. **18**, p. 26, 1933.
194. *Mineral. Mag.* (No. 78), p. 52, December 1913.
195. *Neues Jahrb. Mineral.*, Referate 1, p. 359, 1931.
- 196-223. *Neues Jahrb. Mineral.*, Beil. Band **55**, Abt. A, p. 63-64, 1927.

The percentage of each molecule is plotted on a triangular diagram. The two corners at the base of the triangle each represent 100% of the major or essential molecules present. The top, or third corner, represents the remaining or accessory molecules. The location of the small circle shows the proportions of the essential components and the sum of the accessory molecules. This circle is plotted by first scaling off the percentages of the two components on the base. From the points obtained lines are drawn parallel to the sides opposite the angles containing the two major molecules, to an intersection. The intersection locates the point. The percentage of each of the three accessory molecules is represented by the length of lines drawn to scale from the circle. There are eight such diagrams; one for garnets from each of the following rock types: 1. Granites and pegmatites; 2. Garnets associated with contact action on siliceous rocks; 3. Biotite schists; 4. Amphibole schists; 5. Eclogites; 6. Kimberlites and peridotites; 7. Various basic igneous rocks; 8. Calcareous rocks.

## CONCLUSIONS

1. This study shows the remarkable constancy of one variety of garnet in each rock type. Also this observation demonstrates that the recognition of the rock type is an important aid in determining the chemical composition of garnets by physical methods.

2. Spessartite and almandite constitute 85-90% of the molecules of garnets from pegmatites and granites. In general, if one of the major constituents is known, either spessartite or almandite, the other can be estimated within a reasonable error, with 5-15% left for the remaining molecules. This can be accomplished quickly by determining the amount of almandite through a ferrous iron determination.



3. Since grossularite and andradite represent over 90% of the garnet molecules in calcareous contact rocks, it is possible to estimate the composition by determining the index of refraction alone. Winchell's<sup>4</sup> diagram shows that the index of pure grossularite is 1.734, while that for andradite is 1.895. A straight line diagram represents the proportions of the two garnets. The range of index is so wide and the amounts of other garnet molecules so small that it is nearly always possible to estimate very closely the percentage of grossularite and andradite in garnets from calcareous contact rocks.

<sup>4</sup> Winchell, *Optical Mineralogy*, Part 2, p. 257.



FIG. 1. Garnets from pegmatites and granites.

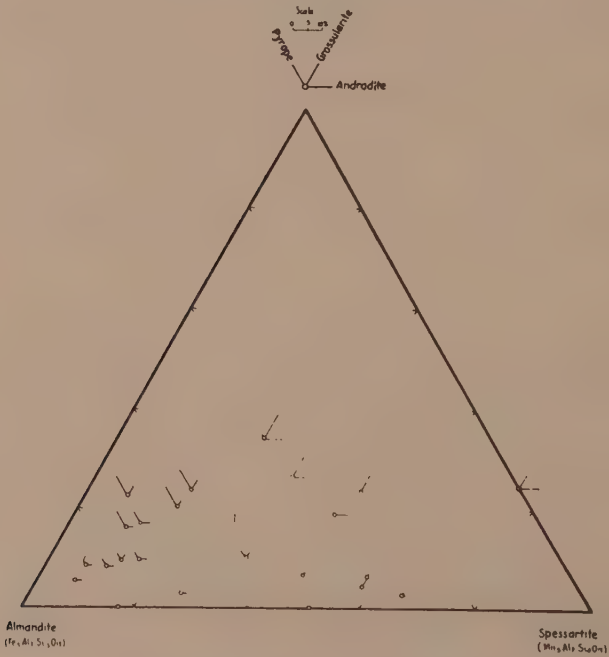


FIG. 2. Garnets from contact action on siliceous rocks.

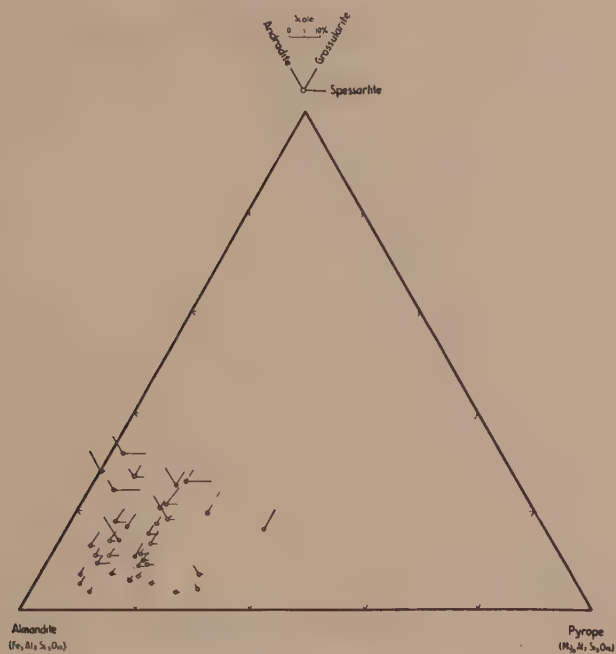


FIG. 3. Garnets from biotite schists.

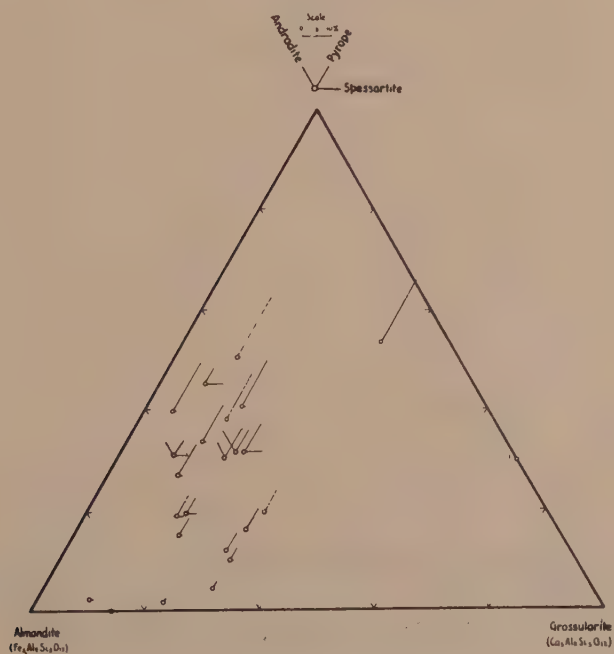


FIG. 4. Garnets from amphibole schists.



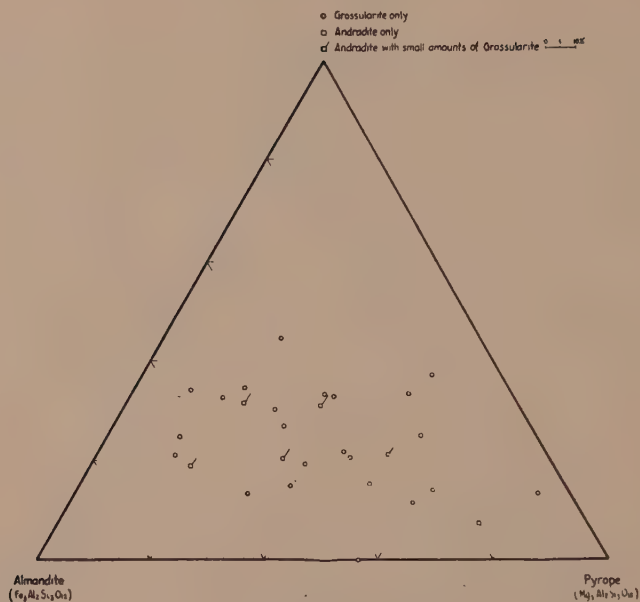


FIG. 5. Garnets from eclogites.

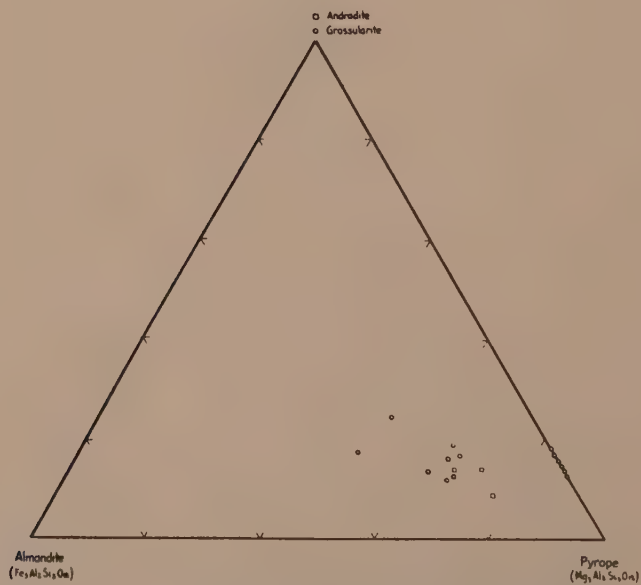


FIG. 6. Garnets from kimberlites and peridotites.

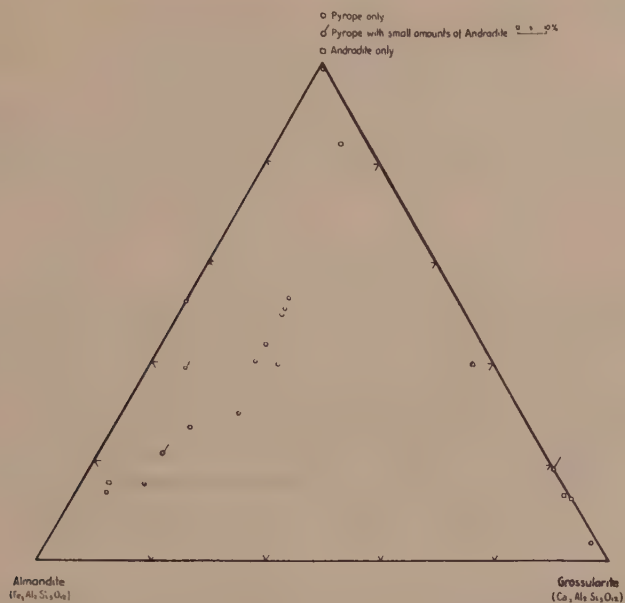


FIG. 7. Garnets from basic igneous rocks.



FIG. 8. Garnets from calcareous rocks.

## ORTHOPYROXENES OF THE BUSHVELD TYPE\*

H. H. HESS AND A. H. PHILLIPS,  
*Princeton University, Princeton, New Jersey.*

The orthopyroxenes of the Bushveld Complex, Transvaal; Stillwater Complex, Montana; Bay of Islands Complex, Newfoundland; Great Dyke of Southern Rhodesia; peridotites of Cuba and most of the other mafic plutonic bodies thus far examined by the writers, have a peculiar striated or laminated appearance in a thin section and exhibit certain abnormal extinction angles. Much confusion concerning these pyroxenes exists in the literature. Niggli, Johannsen, Scholtz, and Chudoba, for example, state that the optic plane is parallel to 100, whereas Larsen, Winchell, Dana, and others place the optic plane of orthopyroxenes parallel to 010.† The laminated appearance and small extinction angles have been considered to be the result of twinning on a very fine or sub-microscopic scale; and the mineral, though outwardly appearing to be orthorhombic, is interpreted as monoclinic. Chudoba suggests that the lamination is due to polysynthetic twinning with translation parallel to 100 (1).

The purpose of this paper is to give an explanation for the lamination, anomalous extinction angles and optical orientation of the constituents, as well as to present data on the chemical composition and optical properties of a few typical examples of such pyroxenes. Certain conclusions are drawn as to the physical chemistry of their crystallization with respect to their mode of occurrence.

### DISCUSSION OF OPTIC PROPERTIES

A careful examination of these orthopyroxenes in thin section definitely shows that the lamination is entirely due to the presence of very fine lamellae of another mineral. These lamellae form closely spaced thin sheets, about .002 mm. thick, parallel to the optic plane of the orthopyroxene. It is difficult to determine the orientation of the optic plane, and not surprising that there is disagreement as to whether it is parallel to 100 or 010. One must determine from a basal section whether the optic plane bisects the obtuse angle ( $92^\circ$ ) of the prismatic cleavages or the acute ( $88^\circ$ ).<sup>1</sup> In the former case the optic plane is parallel to 010, and

\* Contribution No. 1 of a series of papers under preparation by the writers dealing with the optical and chemical properties of rock-forming minerals. Index of refraction and optic angle curves for the orthopyroxenes will be dealt with in a later paper and therefore are not included here.

† See footnote at end of paper.

<sup>1</sup> In some cases where the pinacoidal partings are present, the obtuse angle between the apparent prismatic cleavages seems to be abnormally large, as though they were not true cleavages but sets of cracks diagonal to the two directions of parting.



in the latter to 100. The prismatic cleavages often appear slightly irregular in thin section, and the difference between  $92^\circ$  and  $88^\circ$  is not very great. Obviously the determination must be made on a section exactly perpendicular to the cleavages, or one rotated to that position on a universal stage. A number of such determinations made by the writers on a pyroxene from the Stillwater and Bay of Islands show the optic plane to be parallel to 010.

#### NATURE OF THE LAMELLAE

The lamellae have approximately the same mean index as the orthopyroxene host (regardless of the proportion  $\text{En:Fs}$  in the host) since they are barely visible, if at all, in plane polarized light, and have somewhat higher birefringence. They have large extinction angles, so it

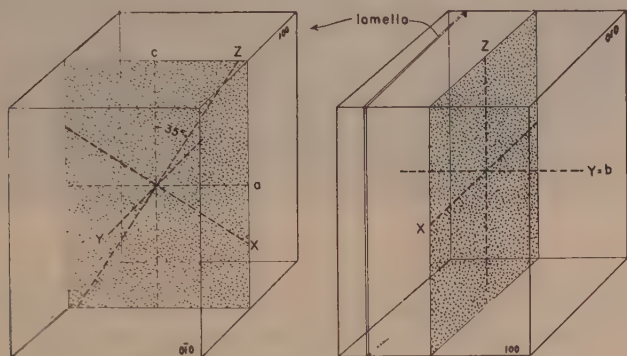


FIG. 1

appears that they are monoclinic pyroxenes, probably of the diopside-hedenbergite series with approximately the same  $\text{Mg/Fe}$  ratio as the host. The orientation of the lamellae is such that the "a" axis of the orthopyroxene coincides with the "b" axis of the clinopyroxene lamellae, and the optic plane of the clinopyroxene is parallel to 100 of the orthopyroxene, as shown in Fig. 1.

#### EFFECT OF LAMELLAE ON OPTICAL PROPERTIES

A large proportion of sections of random orientation will have a banded appearance under crossed nicols, and adjacent bands will extinguish in different positions making angles which will commonly lie between  $0^\circ$  and  $15^\circ$  from the trace of the cleavages. If an attempt is made to locate the principal optical directions on two such adjacent bands by standard universal stage methods, one would find that two, or perhaps all three, of these directions would fall on the stereographic

projection at slightly different points. From such observations one might logically conclude that we were dealing with a polysynthetically twinned pyroxene of monoclinic rather than orthorhombic crystal structure. Scholtz (2) shows such a projection. Actually one would be observing a composite effect produced by the lamellae and orthopyroxene when viewed from a position where the lamellae are dipping at low to moderate angles to the plane of the section. In such sections a definite outcrop of the lamellae is not seen.



FIG. 2

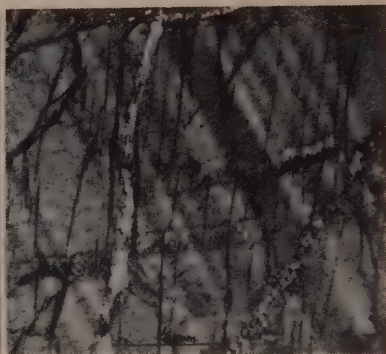


FIG. 3

FIG. 2. Section parallel to 100 under crossed nicols. Fine lamellae of clinopyroxene visible at extinction position of orthopyroxene. Note that lamellae die out near borders of crystal. Photograph exaggerates thickness of lamellae somewhat. ( $\times 25$ )

FIG. 3. Section inclined to all three axes. The lamellae of clinopyroxene here are dipping at a low angle to section giving the appearance of twinning lamellae. ( $\times 78$ )

The extinction angles of this orthopyroxene may thus be explained by the composite effect mentioned above, and by the normal extinctions which may be observed in any orthorhombic crystal with prismatic cleavage in sections equivalent in position to a pyramid. It should be noted that if the cleavage is more than  $30^\circ$  from the normal to the section, its trace will not be visible in the section lying flat on the microscope stage.

TABLE 1. SUMMARY OF OPTICAL OBSERVATIONS ON ORTHOPYROXENE AND LAMELLAE

1. *Section exactly parallel to 001*

- a. Extinction directions bisect angles between prismatic cleavages.
- b. Parting parallel to 100 and 010, common.
- c. Lamellae cannot be seen.
- d. Interference figure: bisectrix perpendicular to section,  $2V$  very large.
- e.  $Z$  perpendicular,  $X$  direction bisects obtuse cleavage angle and  $Y$  bisects acute cleavage angle. ( $X=a$ ,  $Y=b$ ,  $Z=c$ , optic plane 010.)

2. *Section inclined a few degrees to 001 toward 100*
  - a. Straight, fine lamellae appear parallel to X.
3. *Section parallel to 100* (Fig. 2)
  - a. Extinction is parallel to cleavage.
  - b. At the extinction position bright lamellae are seen parallel to cleavage appearing as sharp, fine, straight lines. (This proves the lamellae are parallel to 010.)
  - c. The lamellae themselves extinguish at about 40° either side of the *c* axis of the orthopyroxene.
  - d. The lamellae are brighter (i.e., have higher birefringence) and sharper in this section than in any other section.
  - e. Interference figure of orthopyroxene: bisectrix perpendicular to section, 2V very large. Figure slightly affected by the lamellae when optic plane of orthopyroxene is in N-S or E-W position. Otherwise it is normal.
4. *Section parallel to 010*
  - a. No lamellae visible.
  - b. Highest birefringence for orthopyroxene (1st order yellow).
  - c. Extinction parallel to *c*.
5. *Section displaced from 010 toward 110* (Fig. 3)
  - a. Effect of lamellae becomes visible as broad indistinct darker and lighter bands parallel to cleavage. Bands show small extinction angles to cleavage ( $\pm 5^\circ$ ). Acutal outcrop of lamellae not discernible. (Such sections could easily be mistaken for polysynthetically twinned pyroxene.)
6. *Section displaced from 010 toward pyramid*
  - a. Same as 5, but bands are inclined to cleavage.

TABLE 2. CHEMICAL COMPOSITION

	I	II	III	IIIa	IIIb	IV
SiO <sub>2</sub>	53.61	54.68	53.60	—	53.75	54.63
Al <sub>2</sub> O <sub>3</sub>	1.67	1.80	3.51	—	3.66	2.39
Fe <sub>2</sub> O <sub>3</sub>	1.48	0.50	0.79	—	0.83	1.71
FeO	6.70	9.19	11.38	—	11.91	7.07
MgO	33.15	30.19	25.34	—	26.55	30.30
CaO	2.32	2.22	(4.19)	2.19	2.19	2.20
Na <sub>2</sub> O	0.04	0.04	0.25	—	0.26	0.45
K <sub>2</sub> O	0.06	0.03	0.03	—	0.03	0.11
H <sub>2</sub> O+	0.54	0.46	0.27	—	0.28	0.52
H <sub>2</sub> O—	0.08	0.05	0.04	—	0.04	—
TiO <sub>2</sub>	0.09	0.11	0.29	—	0.30	0.36
P <sub>2</sub> O <sub>5</sub>	tr.	0.02	—	—	—	0.12
Cr <sub>2</sub> O <sub>3</sub>	0.38	0.47	—	—	—	—
MnO	0.16	0.21	0.19	—	.20	0.14
	100.28	99.97	99.88		100.00	100.00

I. Bronzite, chromite horizon, Mountain View Lake, Stillwater Igneous Complex, Montana. Collected by E. Sampson. Field No. M.V.L. 3a. Impurities, a little chromite. Analyst, A. H. Phillips.



- II. Bronzite, near chromite horizon at Dunham's house, Boulder Valley. Collected by J. W. Peoples. Impurities, a little chromite. Field No. 465-E-3h. Reference J. W. Peoples, Ph.D. thesis, Princeton University. Analyst, T. Kameda.
- III. Bronzite from norite, higher in complex than I, near top of Banded Zone, East Boulder Plateau. Collected by Hess. Impurity, small individual crystals of diopsidic monoclinic pyroxene. Field No. EB 32A. Analyst, A. H. Phillips.
- IIIa. Determination of CaO of specimen II from small sample from which an impurity, diopsidic pyroxene, was carefully removed.
- IIIb. Recalculated minus the diopside.
- IV. Average bronzite from Daly.

The following features may be noted in the analyses:

1. They contain rather uniformly about  $2\frac{1}{4}$  per cent of CaO, which is equivalent to a little less than 9 per cent of the diopsidic molecule.
2. Calculation of the "norms" of these analyses shows a considerable SiO<sub>2</sub> deficiency, equivalent to about 10 per cent of the orthosilicate molecule. No explanation of this is apparent. Deficiency in silica is a common attribute of orthopyroxenes; see Fenner, p. 376 (3).
3. The presence of a considerable amount of Al<sub>2</sub>O<sub>3</sub> and a smaller amount of Fe<sub>2</sub>O<sub>3</sub>, which are not present in ideal orthopyroxenes, may be noted as well as a little Na<sub>2</sub>O and K<sub>2</sub>O.
4. The Cr<sub>2</sub>O<sub>3</sub> in I and II is present as an impurity, in the form of minute chromite grains. No chromite was associated with III.
5. TiO<sub>2</sub> increases with the increase in FeO, but is always small.

Only feature number 1 has a direct bearing on the problem at hand. The uniform occurrence of approximately 9 per cent of the diopsidic molecule in the orthopyroxenes can logically be referred to the fine lamellae of clinopyroxene noted in the optical examination. These lamellae, it was estimated in the optical analysis, make up about 10 per cent of the total pyroxene by volume.

Since these orthopyroxenes are Mg-Fe pyroxenes with a relatively small amount of Ca, some clue as to their origin may be obtained from Bowen's and Schairer's work on the system FeO-MgO-SiO<sub>2</sub> (4). Their Fig. 8 is particularly instructive. Considering that portion of the diagram where the MgO:FeO ratios are similar to those present in the orthopyroxenes under discussion, it is found that in this region a clinopyroxene crystallizes at a temperature slightly above 1500°, which in turn inverts to an orthopyroxene in the neighborhood of 1130°C. In view of these facts, two possible explanations of the development of the laminated orthopyroxenes can be suggested: (1) That a clinopyroxene of the pigeonite type crystallized first, which on slow cooling inverted to orthopyroxene with the segregation of diopsidic lamellae; and (2) that crystallization took place originally below the inversion temperature, so that an orthopyroxene separated which was capable of holding in solution

diopsidic pyroxene to the extent of 9 per cent, but on further cooling, exsolution of this calcic pyroxene took place to form the clinopyroxene lamellae. Of the two possibilities, the writers favor the second, inasmuch as a clinopyroxene of diopsidic nature is found also in separate individual crystals in the rocks containing the orthopyroxene. It seems unlikely that two similar clinopyroxenes would separate simultaneously from a magma under conditions of equilibrium resulting from slow cooling and crystallization.

References in the literature and examinations of slides at Princeton University indicate that laminated orthopyroxenes similar to those here described are characteristic of large deep-seated, slowly cooled intrusives, whereas they do not occur in lavas or near-surface dikes and sills. The orthopyroxenes of the latter group are always uniform and not laminated, although they may show relatively coarse intergrowths with clinopyroxene or possess other peculiarities, such as inclined extinction described by Verhooogen (5), the explanations of which are beyond the scope of this paper. The absence of these laminated orthopyroxenes in volcanic and near-surface igneous rocks may be ascribed to the relatively rapid cooling of these rocks which does not permit the exsolution of the diopsidic lamellae. It would be interesting to determine especially the CaO content of a number of orthopyroxenes of such rocks to determine if this postulate is correct.

In order to test this hypothesis, the writers collected from the literature a number of analyses which they considered reasonably reliable. The result showed that thirteen orthopyroxenes from plutonic igneous rocks average 2.15 per cent CaO; while eleven from volcanics gave 2.28 per cent CaO. This clearly suggests that orthopyroxenes, whether they show the lamellae or not, nevertheless contained originally about the same amount of the diopsidic molecule. No very great validity, however, can be attached to the absolute values of the averages inasmuch as individual analyses vary by as much as  $1\frac{1}{2}$  per cent either side of the mean. A number of very accurate determinations of the CaO content of these pyroxenes are needed on material free from contamination of the monoclinic pyroxene which is nearly always present in the original rock. There is some indication of a slight increase in the CaO content with increase in FeO, or in respect to the magmas from which they crystallize, orthopyroxenes in diorites tend to have more CaO than those in gabbros, norites, etc. Orthopyroxenes from rocks which the writers consider to be derived from an ultramafic magma, show in some cases the normal  $2\frac{1}{4}$  per cent CaO, and in others much lower values. It is suggested that CaO is soluble in those pyroxenes to the extent of  $2\frac{1}{4}$  per cent, but that in many cases the original magma did not have this amount of CaO.

In many cases, orthopyroxenes low in CaO, have conspicuously few lamellae, so that they can be recognized in thin section without the necessity of an analysis.

#### SUMMARY

Orthopyroxenes of the Bushveld type are not polysynthetically twinned monoclinic pyroxenes, but are truly orthorhombic, at least so far as their optical properties are concerned. The laminated appearance, apparently twinning, is actually the result of the presence of thin lamellae of a clinopyroxene oriented parallel to the optic plane of the orthopyroxene. The optic plane is parallel to 010. The small anomalous extinction angles are a result of the composite effect of lamellae and host where the lamellae are inclined at low to moderate angles to the plane of the section. Pyroxenes of this type occur in slowly cooled plutonic igneous rocks, whereas orthopyroxenes of volcanics do not have such lamellae. Chemical analyses of orthopyroxenes from both sources show approximately  $2\frac{1}{4}$  per cent of CaO, or a little less than 9 per cent of the diopsidic molecule. It is suggested that this represents the solubility of the diopsidic molecule in Mg-rich orthopyroxenes at high temperatures. With slow cooling this diopsidic material is exsolves and forms the lamellae.

NOTE: Since the completion of the manuscript it has been noted that, following Goldschmidt, German texts orient orthopyroxenes so that "a" axis is longer than "b" axis, whereas Dana and most English language texts make "a" the shorter axis. This accounts for the fact that some authors considered the optic plane to be parallel to 100, and others, parallel to 010. It depended upon which orientation they had adopted and not on any differences in observation. The present authors have used Dana's orientation in this paper, though it is now apparent that the other orientation would be advisable considering the relationship between the lamellae and orthopyroxene host.

#### REFERENCES

1. CHUDOKA, K., *Gesteinbildende Mineralien*. 1932. Herder & Co., Freiburg.
2. SCHOLTZ, D. L., The magmatic nickeliferous ore deposits of East Griqualand and Pondoland: Pt. 1. *Trans. and Proc. Geol. Soc. of S. Africa*, vol. 39, pp. 81-210, 1936.
3. FENNER, C. N., Olivine fourchites from Raymond Fosdick Mountains, Antarctica: *Bull. Geol. Soc. Am.*, vol. 49, pp. 367-400, 1938.
4. BOWEN, N. L. and SCHAIRER, J. F., The system  $MgO-FeO-SiO_2$ : *Am. Jour. Sci.*, vol. 29, pp. 151-227, 1935.
5. VERHOOGEN, J., Monoclinic "hypersthene" from Cascada Lavas: *Am. Jour. Sci.*, vol. 33, pp. 63-69, 1937.





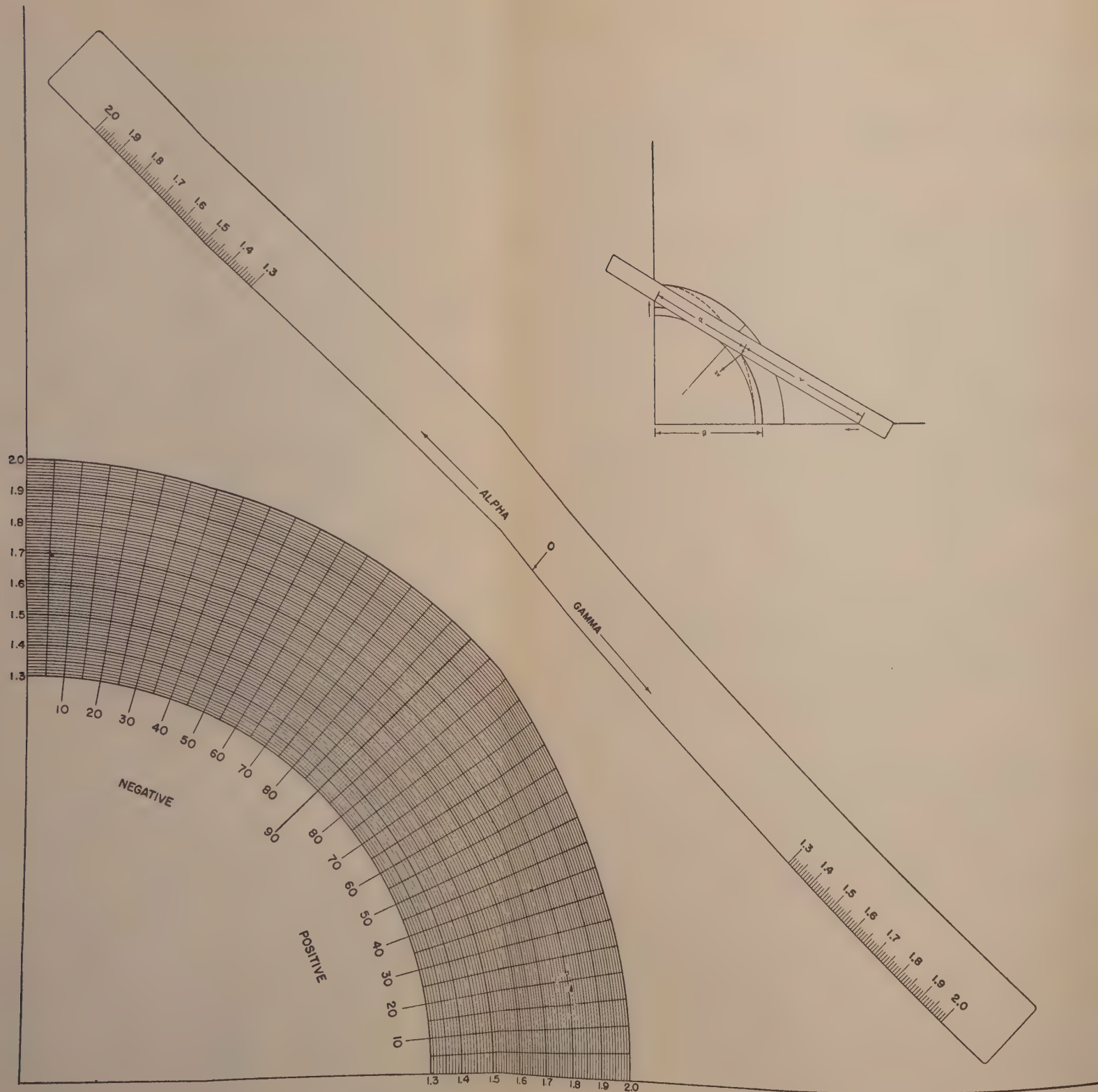


FIG. 1

# GRAPHIC METHOD OF DETERMINING OPTIC SIGN AND TRUE AXIAL ANGLE FROM REFRACTIVE INDICES OF BIAxIAL MINERALS

J. H. LANE, JR., AND H. T. U. SMITH,  
*University of Kansas, Lawrence, Kansas.*

## INTRODUCTION

The axial angle and optic sign of any biaxial mineral are functions of the refractive indices, as may be expressed by the equation<sup>1</sup>:

$$\text{Tan}^2 V_a = \frac{\alpha^2(\gamma^2 - \beta^2)}{\gamma^2(\beta^2 - \alpha^2)}.$$

The same relation may be expressed approximately by the simpler equation<sup>2</sup>:

$$\text{Tan}^2 V_a = \frac{\gamma - \beta}{\beta - \alpha}.$$

In general, the second equation is more convenient to use, and its application has been facilitated by Wright's graphic solution,<sup>3</sup> later simplified by Smith.<sup>4</sup> The approximate equation, however, whether solved graphically or by computation, involves a certain element of error, which varies directly with axial angle and with total birefringence, and reaches serious proportions in minerals of relatively high birefringence.<sup>5</sup> To avoid these errors and yet retain speed and simplicity of operation, a graphic solution for true axial angle is here introduced.

The graphic solution described below was developed by Lane as a student in Smith's class in optical mineralogy. The manuscript was prepared in collaboration.

## DESCRIPTION

The graphic method here presented (Fig. 1) employs two separate parts: a graphic plot, and a graduated scale which is adjusted to the plot for each determination.

<sup>1</sup> Johannsen, Albert, *Manual of petrographic methods*, McGraw-Hill, New York, p. 104; Rosenbusch, H., and Wülfing, E. A., *Mikroskopische Physiographie der Petrographischen Wichtigen Mineralien*, Band 1, Erste Hälfte, E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 1924, p. 120.

<sup>2</sup> Rosenbusch and Wülfing, *op. cit.*, p. 121.

<sup>3</sup> Wright, F. E., Graphical methods in microscopical petrography: *Am. Jour. Sci.*, vol. 36, pp. 509-39, 1913.

<sup>4</sup> Smith, H. T. U., Simplified graphic method of determining approximate axial angle from refractive indices of biaxial minerals: *Am. Mineral.*, vol. 22, pp. 675-81, 1937.

<sup>5</sup> Larsen, E. S., The microscopic determination of the nonopaque minerals: *U. S. Geol. Surv., Bull.* 679, pp. 10-11, 1921.

The graphic plot consists simply of a series of concentric 90 degree arcs whose radii are proportional to refractive indices within the range 1.3 to 2.0. A radial line bisecting the arcs marks the boundary between the positive and negative field. Each set of 45 degree arcs is in turn subdivided by radial lines into 18 equal sectors, representing axial angles from 0 to 90 degrees in 5 degree intervals, the ratio being 1 degree of arc equals 2 degrees of axial angle.

The graduated scale consists of a strip of stiff drawing paper on which values of indices in the range 1.3 to 2.0 are marked off in both directions from a medial zero point, in the same units as used on the graphic plot. The distance from the zero point to the value for any index will then equal the radius of the arc corresponding to that same index on the graphic plot. To mark the values of indices for particular determinations, sliding pointers of heavy drawing paper may be constructed, and equipped with slits through which the scale is inserted. In preparing the scale, it is essential that one edge be a true straightedge.

The procedure in using the graphic method is indicated by the guide sketch accompanying the chart, and is outlined below:

1. On the graduated scale, mark the value of  $\alpha$  to the left of the zero point, and the value of  $\gamma$  to the right of the zero point. These values may be marked either with sliding cardboard pointers or with a pencil.

2. Place the scale on the graphic plot so that the value of  $\alpha$  lies on the ordinate and value of  $\gamma$  on the abscissa. Keeping these values on the lines indicated, move the scale until its zero point cuts the arc which represents the value of  $\beta$ .

3. From the intersection determined above, follow the radial line to the inner quadrantal scale, on which optic sign and axial angle may be read directly. Values intermediate between the 5 degree lines are interpolated.

#### DERIVATION

The graphic solution presented above is based on the geometric properties of the biaxial indicatrix, which is a triaxial ellipsoid. In the *alpha-gamma* cross section, or optic plane of the indicatrix, it may be seen that the angle between the two primary optic axes is the same as the angle between the traces of the two circular sections. It follows that the acute angle between the acute bisectrix and one optic axis equals the acute angle between the obtuse bisectrix and the trace of a circular section, and that twice the latter equals the axial angle. In the accompanying graphic plot, it is actually the angle between the obtuse bisectrix and the trace of the circular section which is measured, and then doubled. The trace of the circular section corresponding to any particular set of



indices is located by finding the intersection of a circle of radius equal to  $\beta$  with the ellipse whose semiaxes represent  $\alpha$  and  $\gamma$ .<sup>6</sup> On the graphic plot, the circle used for any particular determination is selected from a series of circles, or rather arcs, whose radii represent different values of  $\beta$ .

The sliding scale is simply a device to describe ellipses for any set of values of  $\alpha$  and  $\gamma$ . It is based on the proposition that the figure traced by any point on a straight line of fixed length, moving so that its ends remain in the coordinate axes, is an ellipse whose semiaxes equal the distances from the point to the two ends of the line, respectively.<sup>7</sup> In practice, only a single point on the ellipse—the point where it intersects the circle of radius  $\beta$ —is desired, and the sliding scale is moved only far enough to locate that point. This point, once determined, locates the trace of the circular section, from which the desired acute angle with respect to one of the coordinate axes is noted.

#### ACCURACY

The accuracy of the graphic solution described above is qualified by two factors: (1) the accuracy of the laboratory data used, and (2) the degree of precision with which the chart may be read. Factors influencing

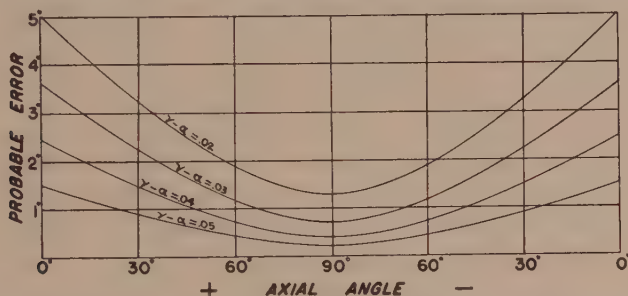


FIG. 2. Curves showing approximate amount of error introduced by inaccuracies in reading the graphic chart, as estimated from about one hundred trial determinations using assumed values.

the accuracy of laboratory determinations of indices have been noted by the senior author in a previous paper.<sup>8</sup> Here it need only be said that the accuracy of the graphic solution varies directly with the ratio between total birefringence of the mineral and the maximum possible error in measurements of indices.

<sup>6</sup> For proof, see Johannsen, *op. cit.*, pp. 92–93, 102.

<sup>7</sup> Given as a problem in textbooks on analytic geometry.

<sup>8</sup> Smith, H. T. U., *op. cit.*, p. 678.

The accuracy attainable in reading the graphic chart depends on the sharpness of the intersection between the circle and the imaginary ellipse described by the zero point on the sliding scale. This varies directly with axial angle and with total birefringence, and varies inversely with the relative thickness of the lines with respect to the scale of the graph. The approximate amount of error introduced by these factors is shown in Fig. 2. Only when the total birefringence is less than about .03 do the errors incident to this factor reach serious proportions.

In summary, the accuracy of the graphic solution here presented is maximum where that of Smith's approximate graphic method is minimum, and vice versa. The two methods thus conveniently supplement one another.

#### APPLICATIONS

The applications of the graphic method here introduced are similar to those of the approximate graphic method, previously discussed,<sup>9</sup> except that it is best suited to minerals whose birefringence is relatively high. In short, it may be used (1) to determine  $2V$  when this quantity is not directly measurable; (2) to determine a third index when two indices and  $2V$  are known; and (3) to check the mutual consistency of optical constants when all are directly determined by standard methods. For the teacher, a further application lies in its value as a means of elucidating the geometry of the biaxial indicatrix.

<sup>9</sup> Smith, H. T. U., *op. cit.*, p. 679.

## NOTES AND NEWS

### DIASPORE CLAY CAST OF FOSSIL WOOD IN A MISSOURI DIASPORE PIT

W. D. KELLER, *University of Missouri, Columbia, Missouri.*

The fire clay deposits of Missouri, including the plastic, flint, and diaspoire clays, are strikingly barren of fossils (excepting coal) within the clay itself. Their absence is not surprising because the removal, by leaching, of hard parts of organic remains is to be expected in all of the refractory clays, and particularly so in the diaspoire pits where leaching is believed to have been so effective as to remove silica from the kaolinite-halloysite type of clay and leave the alumina-rich diaspoire. Obviously this alteration is chemically similar to laterization,<sup>1</sup> and since this is a so-called end process of weathering because of its severity, little of the original material is to be expected to remain intact.

The finding of a specimen of "petrified (?)" wood, a filling of a cavity by diaspoire clay formerly occupied by wood, buried within a diaspoire pit was so unusual as to be deemed worthy of description. Inquiry of clay miners long experienced in the diaspoire region revealed no previous knowledge of a similar occurrence, and a like negative report was given by Mr. McQueen, assistant state geologist. It is the first reported preservation of its kind known to the writer.

The specimen under report was taken by Mr. A. O. Bledsoe, mining contractor of Belle, Missouri, from the Morre clay pit about five miles north of Drake, Missouri. During the mining operation clay containing a small amount of the casted wood material was removed and shipped by workmen who did not realize the uniqueness of their find. Only by accident was the small specimen now at hand saved until Mr. Bledsoe, in charge, returned to inspect the pit. He recognized the unusual filling and sought to recover additional material, but all had been mined and shipped. This part of the Morre pit is now exhausted. Therefore, the specimen to be described is the only one of its kind known to us.

It is a fragment of what was a limb, or stem of a plant, once enclosed but now set to a depth longitudinally of one-third to one-half its diameter within a small clay boulder broken out in mining. The "limb" is roughly circular in cross section, approximately 4.5 cm. in diameter, and is broken to a length of 10 cm. (Fig. 1). There is no appreciable change in diameter size throughout the length, so the original piece must have been con-

<sup>1</sup> McQueen, H. S., Geologic relations of the diaspoire and flint fire clays of Missouri: *Jour. Amer. Cer. Soc.*, vol. 12, pp. 687-697, 1929.

Allen, V. T., Mineral composition and origin of Missouri flint and diaspoire clays: *Appendix IV, 58th Biennial Report, Missouri Geological Survey, 1935.*

siderably longer. Apparently the wood was at one time buried, later removed but leaving a mold which was later filled with clay material. No wood texture is preserved internally (even microscopically in thin section), but the ribs, irregularities, and texture of the bark are exceptionally well displayed. It twists with a weak right-hand spiral. Some carbonization of the bark took place and this acts as the parting between mold and cast.

Definite identification of the fossil has not been made but Dr. Charles B. Read of the U. S. Geological Survey has reported that it could easily be a "stigmara."



FIG. 1. Fossil wood cast in diaspore clay.

The Morre clay pit was what is known as a coal-bearing, "mixed" pit. A body of soft coal about 40 feet by 25 feet in area and 12 feet deep lay with flint clay at the top of the pit which was roughly 300 feet in diameter and 170 feet in depth. The "petrified wood" occurred at a depth of about 35 feet within the mixed first grade (about 70%  $\text{Al}_2\text{O}_3$ ) and second grade (about 60%  $\text{Al}_2\text{O}_3$ ) diaspore clay. The specimen will probably contain about 65%  $\text{Al}_2\text{O}_3$ . As was previously stated, the pit as a whole was also "mixed," i.e., contained many alternating, discontinuous lenses and layers of first and second grade diaspore and burley (about 50%  $\text{Al}_2\text{O}_3$ ) clay.

The mechanism of the casting offers some interesting relations to the origin of the clay in the pit. If the removal of the wood and filling of the mold took place while the available and surrounding material was still kaolinite or halloysite, the theoretical reduction in volume upon leaching to 65%  $\text{Al}_2\text{O}_3$  diaspore should have been one-half. The volume reduction was computed on a density basis of 2.6 for kaolinite and 3.4 for diaspore. If leaching of the cast and the mold took place uniformly their fit should



have remained tight, which is roughly now the case. The present volume of the "wood" should be reduced one-half, but the less altered bark should be shrunk like the skin of a drying apple. Perhaps a part of the crenulation of bark is due to this action, although it is doubtful if the volume has been reduced one-half. The writer believes there has been an appreciable amount of alumina freed for solution during the silicate clay hydrolysis and breakdown, and this soluble alumina, after migrating, has been deposited in part of the space left by the removal of silica. Slumping within the clay pit has filled a total of the space vacated by dissolved alumina. Evidence for solution of alumina is the occasional presence of limestone and chert boulders in the pits partially replaced by alumina.

An alternative to the filling of the mold before leaching, would be filling after conversion of the clay to the present diaspore. This would eliminate the problem of volume reduction but introduces one with the bulk transportation of diaspore—not easily solved if our ideas of the transportation of solid hydrated alumina are true. Since a thin section of clay taken across the "wood" appears the same as the enclosing material it seems that filling took place prior to leaching. The writer considers this corroborative evidence for the preferred first mechanism of casting.

## NOTES ON SOME ADELIE LAND ROCKS

DUNCAN STEWART, JR.

*Michigan State College, East Lansing, Michigan.*

Adelie Land, Antarctica, lies to the south of Australia, and is an area bounded by the parallels  $66^{\circ}$  and  $67^{\circ}$  S., and the meridians  $136^{\circ}20'E.$  and  $142^{\circ}20'E.$  It was annexed to France by decree of March 27, 1924.<sup>1</sup> Stillwell<sup>2</sup> refers to Adelie Land as a portion of the Antarctic Continent which lies in the region surrounding Longitude  $143^{\circ}$  and Latitude  $67^{\circ}$ .

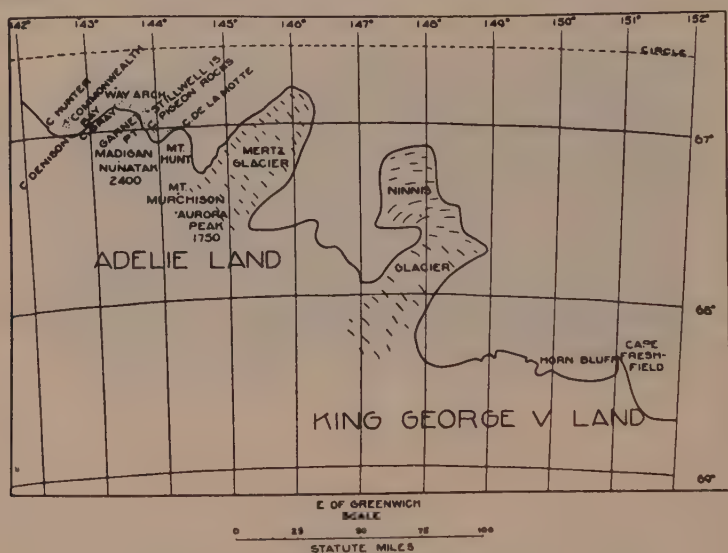


FIG. 1. Sketch map of Adelie Land and King George V Land.

However, points, as Cape Denison and Madigan Nunatak, lying to the east of  $142^{\circ}20'$ , are included by the Australasian Expedition as being in Adelie Land. Hobbs<sup>3</sup> has made an intensive study of the literature pertaining to this sector of the Antarctic, and the claims of the United States, the British and the French. Figure 1 is a sketch map of the area under consideration.

<sup>1</sup> Joerg, W. L. G., Brief history of polar exploration since the introduction of flying. Second, revised, edition: *Am. Geogr. Soc. Special Pub.*, No. 11, p. 70, 1930.

<sup>2</sup> Stillwell, F. L., The metamorphic rocks of Adelie Land: Australasian Antarctic Expedition, 1911-1914, *Scientific Reports*, Series A.—Geography, Physiography, Glaciology, Oceanography, and Geology, vol. 3, Part 1, p. 7, 1918.

<sup>3</sup> Hobbs, W. H., Wilkes Land rediscovered: *Geogr. Rev.*, vol. 22, No. 4, pp. 632-655, 1932.

The Adelie Land basement is a complex of gneisses and schists of probable pre-Cambrian age, which was derived from sedimentary rocks, acid intrusives, diorites and dolerites. A large number of specimens of these metamorphic rocks were taken from the moraines and the *in situ* occurrences on the coastal nunataks and islets by the Australasian Antarctic Expedition, 1911-1914. Priestley and Tilley<sup>4</sup> record the occurrence of red sandstones in the moraines, indicating the continuation of the Beacon sandstone<sup>5</sup> through Adelie Land. Dolerites were also noted as erratics in the moraines.<sup>6</sup> In preparation are two papers on the granites<sup>7</sup> and the sedimentary rocks of Adelie Land.<sup>8</sup>

In the University of Michigan Collections there are 12 duplicate rock specimens collected by the Australasian Expedition. The various specimens gathered by the Expedition have been reported on in part by Stillwell<sup>9,10</sup>, Tilley,<sup>11</sup> Browne,<sup>12</sup> and Coulson.<sup>13</sup>

The following are the specimens in the Collections, the numbers and the terminology are the same as those of the Australasian Antarctic Expedition: 11, granodiorite gneiss, Cape Denison; 135, epidote marble (erratic), Cape Denison; 147, magnetite-garnet schist (erratic), Cape Denison; 402, forsterite marble (erratic), Cape Denison; 629, amphibolite, Cape Denison; 784, garnet-cordierite gneiss, Cape Gray; 785, hypersthene-biotite-feldspar gneiss, Cape Pigeon Rocks; 794, plagioclase-pyroxene gneiss, Madigan Nunatak; 797, hypersthene-alkali-feldspar gneiss, Madigan Nunatak; 950, biotite, hornblende schist (erratic), Cape Denison; 956, biotite-hornblende-feldspar gneiss (erratic), Cape Denison; 983, granite gneiss, Great Mackellar Island.

<sup>4</sup> Priestley, R. E., and C. E. Tilley, Geological problems of Antarctica: Problems of polar research: *Am. Geogr. Soc. Special Pub.*, No. 7, pp. 318-319, 1928.

<sup>5</sup> Stewart, Duncan, Jr., The petrography of the Beacon Sandstone of South Victoria Land: *Am. Mineral.*, vol. 19, pp. 351-359, 1934.

<sup>6</sup> Browne, W. R., The dolerites of King George Land and Adelie Land: Australasian Antarctic Expedition, 1911-1914, *Scientific Reports*, Series A, vol. 3, Geology, Part 3, p. 245, 1923.

<sup>7</sup> Summers, F. H., The granites of Adelie Land and King George Land: *Ibid.*, Part 6, (In preparation).

<sup>8</sup> Mawson, Douglas, The sedimentary rocks of Adelie Land and King George Land: *Ibid.*, Part 7, (In preparation).

<sup>9</sup> Stillwell, F. L., *op. cit.*, 230 pp.

<sup>10</sup> Stillwell, F. L., Amphibolites and related rocks from the moraines, Cape Denison Adelie Land: *Ibid.*, Part 4, pp. 259-280, 1923.

<sup>11</sup> Tilley, C. E., The metamorphic limestones of Commonwealth Bay, Adelie Land: *Ibid.*, Part 2, pp. 231-244, 1923.

<sup>12</sup> Browne, W. R., *op. cit.*, pp. 245-258.

<sup>13</sup> Coulson, A. L., Magnetite garnet rocks from the moraines, Cape Denison, Adelie Land: *Ibid.*, Part 5, pp. 281-305, 1925.

Specimens 11, 629, and 794 have been analyzed chemically and the results published by Stillwell.<sup>14</sup> Comparisons of quantitative mineralogical data and the mineralogical compositions computed from the chemical analyses of these specimens have been recorded.<sup>15</sup> Table 1 shows the mineralogical compositions of eleven of the metamorphic rocks.

TABLE 1. MINERALOGICAL COMPOSITION OF SOME METAMORPHIC ROCKS FROM ADELIE LAND

Mineral	Specimen										
	11	135	402	629	784	785	794	797	950	956	983 <sup>a</sup>
Quartz	42.80	p	—	p	p	p	p	p	p	p	26.55
Orthoclase	—	—	—	—	p	p	—	p	—	p	p
Microcline	22.30	p	—	—	p	p	—	—	—	p	62.98
Perthite	—	—	—	—	p	—	—	p	—	—	—
Albite	—	—	—	—	—	—	p	—	—	—	—
Oligoclase	20.17	—	—	—	—	—	—	p	—	p	p
Andesine	—	—	—	25.53 <sup>c</sup>	—	p	49.01 <sup>c</sup>	—	—	—	—
Plagioclase (undet.)	—	p	—	p	p	—	—	—	24.54 <sup>c</sup>	—	—
Muscovite	0.85	—	—	—	—	—	—	—	—	—	2.56
Biotite	13.87 <sup>b</sup>	—	—	0.35	p	p	—	p	13.05	p	5.87
Chlorite	p	p	—	—	p	p	3.19	—	—	p	—
Green hornblende	—	—	—	72.51	—	—	—	—	54.40	p	—
Glaucophane	—	—	—	—	—	—	—	—	—	—	—
Hypersthene	—	—	—	—	—	p	43.02	p	—	—	—
Augite	—	—	—	—	—	—	—	—	—	—	—
Diopside	—	—	p	—	—	—	—	—	—	—	—
Epidote	p	p	—	0.28	—	p	—	—	p	p	p
Zoisite	—	—	—	p	—	—	—	—	—	—	—
Sphene	p	p	—	0.90	—	—	—	—	—	—	p
Apatite	p	p	—	p	p	p	p	—	2.09	p	2.04 <sup>b</sup>
Zircon	p	—	—	—	—	—	p	p	—	—	p
Tourmaline	?	p	—	—	—	—	—	—	—	—	—
Forsterite	—	—	p	—	—	—	—	—	—	—	—
Cordierite	—	—	—	—	p	—	—	—	—	—	—
Monazite	—	—	—	—	p	—	—	—	—	—	—
Garnet	—	—	—	—	—	p	—	—	—	—	—
Magnetite	p	p	p	—	p	p	—	p	—	p	p
Ilmenite	—	—	—	0.43	p	p	4.68	p	5.92	p	—
Pyrite	p	—	—	—	p	p	abs	p	—	p	—
Limonite	—	p	—	—	—	—	—	p	—	—	—
Hematite	p	—	—	—	—	—	—	p	—	p	—

<sup>14</sup> Stillwell, F. L., *op. cit.*, pp. 86, 41, and 131.

<sup>15</sup> Stewart, Duncan, Jr., The petrography of some Antarctic rocks: *Am. Mineral.*, vol. 19, pp. 150-160, 1934.



Mineral	Specimen										
	11	135	402	629	784	785	794	797	950	956	983 <sup>a</sup>
Serpentine	—	—	p	—	—	—	—	—	—	—	—
Leucoxene	—	—	—	—	p	—	—	—	—	p	—
Delessite (?)	—	—	—	—	—	—	—	p	—	—	—
Calcite	—	p	p	—	—	—	—	—	—	p	p
Dolomite	—	—	p	—	—	—	—	—	—	—	—
Sericite	p	—	—	p	—	p	—	p	p	p	p
Kaolin	p	—	—	—	—	p	—	—	—	—	p
	99.99			100.00			100.01		100.00		100.00

p = present in thin section.

<sup>a</sup> Average of two thin sections.

<sup>b</sup> Includes accessories.

<sup>c</sup> Includes plagioclase and minute amounts of quartz.

## NOTE ON RÖMERITE

C. W. WOLFE, *Harvard University, Cambridge, Mass.*

In the paper on the "Reorientation of Römerite" (*Am. Mineral.*, vol. 22, pp. 736-741, 1937), a misprint in the transformation formula, Goldschmidt to "Normal Setting," p. 740, was overlooked. Instead of  $0\bar{1}0/\bar{1}00/00\bar{1}$ , the formula should read  $0\bar{1}0/\bar{1}10/00\bar{1}$ .

Through an oversight, the study of Robert E. Landon on Römerite (*Am. Mineral.*, vol. 12, pp. 279-283, 1927), was not mentioned. Landon retains Goldschmidt's setting, and his form list may be transformed to the "normal setting" by the above corrected formula. Two of his three new forms  $(120) = (2\bar{1}0)$  and  $(2\bar{1}0) = (1\bar{3}0)$  have been observed by Ungemach and are included in the angle table, but the third new form  $(4\bar{1}0) = (1\bar{5}0)$  has not been observed elsewhere. As his observed value for  $\varphi$  and the calculated value differ by about  $3^\circ$  and as there has been but one observation, the form must be listed as rare or uncertain, and need not be included in the angle table.

## PROCEEDINGS OF SOCIETIES

## NEW YORK MINERALOGICAL CLUB

*The American Museum of Natural History, New York City, May 18, 1938.*

The meeting was called to order by 1st Vice-President Andersen at 8:15 P.M. Sixty-five (65) members and guests were present.

The death of Frederick I. Allen, a very distinguished member of the Club, was announced.

The Field Trip Committee reported a successful field trip to Easton, Pennsylvania, and the plans for a trip to Bedford, New York, on May 29th.

1st Vice-President Andersen then presented the speaker of the evening, Mr. Harry R. Lee, who spoke on *Mineralogy and the Blowpipe Art*.

Mr. Lee, who is an officer of the Club and a research metallurgist, touched successively on the history of the blowpipe art, the present interest in blowpipe methods, blowpipe equipment and its uses, and typical blowpipe tests in the determination of minerals. He also stressed the determinative characters aside from the blowpipe, the necessity of a determinative scheme, the advantages and limitations of the blowpipe and the future of the art in mineral determination. The speaker reviewed the contributions made first in Sweden and then in Germany, by the distinguished chemists and mineralogists who adapted the blowpipe to those sciences and developed the appropriate equipment, reagents and methods, all now well-known and still in use.

The earliest reference to the scientific use of the blowpipe in Europe is found in a pamphlet on Iceland spar, published in Latin in 1670, by a German, Erasmus Bartholin, who mentioned that the mineral proved capable of calcination to lime by the blowpipe flame. In the "Experimental Glassblowing Art," also in Latin, and dated 1679, another German, J. Kunckel, suggested that the glassworker's blowpipe could serve the chemist in the reduction of metallic oxides on charcoal. In "Elements of the Testing Art," again in Latin, and issued in 1739, still another German, Johann Andreas Cramer, described a



blowpipe of copper tubing, fitted with a hollow sphere for retention of moisture from the breath of the operator, and suitable for the fusion of small beads of metallic or other materials.

From 1740 well into the 19th Century all the recorded development of the blowpipe art took place in Sweden, where a succession of distinguished men made it the basis for the remarkable advances in mineralogy and chemistry for which that country and the period are famous. In 1738 Anton Schwab, of the Swedish Bureau of Mines, first applied the art to the testing of ores, but he left no written record. Cronstedt, who used the blowpipe chiefly to identify the elements in minerals, was first to recognize that borax, sodium phosphate and soda are distinctively colored by many of the oxides when dissolved in these fluxes. He, furthermore, standardized the essential equipment and reagents, constructed the first portable kit, and called it the "pocket laboratory." In a book published in 1770, Engestrom collated the mineralogical researches of Cronstedt, and added an introduction to blowpipe analysis—the first comprehensive description of the art. Bergmann, professor of chemistry at the University of Upsala, checked and broadened the methods of Cronstedt, improved the form of the instrument, and in 1779 published all methods in a "Commentary on the Blowpipe." In 1784 Scheele announced the operating difference between the oxidizing and reducing flames. However, publication was soon again outstripped by the accomplishments of Gahn, whose distinguished work laid the basis for use of the blowpipe in chemistry and mineralogy. In addition to his remarkable skill Gahn employed the platinum wire as a support, cobalt nitrate as a coloring reagent, and soda for reduction of oxides. Inasmuch as he published nothing, preservation of the methods and results is due to his pupil Berzelius, who in 1812 made them a section of the first edition of his "Textbook of Chemistry." Pursuing the art with enthusiasm and affection, Berzelius in 1820 published the famous monograph entitled "Use of the Blowpipe in Chemistry and Mineralogy," which appeared in four German editions and was elsewhere widely translated.

Long before the book of Berzelius had appeared in German, the blowpipe had figured prominently in mineralogical, metallurgical and chemical instruction at the famous Mining Academy in Freiberg, Saxony. The new textbook assisted instruction, and stimulated research by Plattner and Harkort, who were students and contemporary teachers at Freiberg. Harkort adapted the silver assay method to the reduced scale that the blowpipe permits, and in 1827 he announced the new method in a monograph entitled "The Art of Assaying with the Blowpipe." Within the next 20 years Plattner had adapted to blowpipe methods furnace assays for gold, copper, lead, bismuth and tin, and had devised a method for the successive assay of iron, cobalt, nickel, copper, silver and gold from a single specimen of cobalt-nickel speiss, then smelted nearby. In the same decade Bunsen, who was a chemist rather than mineralogist, devised and published his methods for the detection of elements by their coloration of the Bunsen flame. Of more importance, Bunsen devised a blowpipe method for volatilizing elements and compounds and condensing them as films, such as certain oxides, sulphides and iodides. Many of these substances are highly colored and strongly characteristic.

The present interest in blowpipe methods rests in their use for the determination of minerals and in the teaching of some of the fundamentals in metallurgy to engineering students, who can readily visualize fusion reactions and other high temperature phenomena that are quickly attainable with the blowpipe.

After a short description of the principal equipment used in blowpipe analysis, the typical tests employed in the determination of minerals were divided into those that use heat with air, and those that utilize flame with fluxes. By metallurgical analogy the closed tube was likened to the muffle furnace, the open tube to the roasting kiln, and the charcoal block to the open hearth.

While the blowpipe art is an important phase of determinative mineralogy, it was pointed out that chemical testing should not be over-emphasized, and an appeal was made for drawing full value from all discernible physical characters of minerals. Determinative characters beyond the blowpipe were shown to be necessary for polymorphic minerals and for those that are chemically similar. The advantages and limitations of blowpipe methods, especially in relation to the chemical composition of minerals, were impartially summarized, and pertinent experiences cited. Finally, the speaker concluded that collegiate instruction in determinative mineralogy shows a strong trend away from the blowpipe and toward entire reliance on physical characters—and regret was implied. Declining to prophesy the future of the blowpipe art, the speaker expressed the hope that it would long survive and that many would use it to widen their present interest and pleasure in the study of mineralogy.

F. H. POUGH, *Secretary*

## NEW MINERAL NAMES

### Bedenite

N. E. EFREMOV: Bedenite—a new mineral (preliminary information). *Mem. Soc. Russe Mineral.*, 2d ser., vol. 66, No. 3, pp. 479–485, 1937, 1 fig. English Summary.

NAME: From the locality, Beden Mountain, North Caucasus.

CHEMICAL PROPERTIES: A silicate of lime, magnesia, iron and alumina:  $\text{Ca}_2(\text{Mg}, \text{Fe}''', \text{Al})_5\text{Si}_3\text{O}_{22}\text{OH}$ . Analysis:  $\text{SiO}_2$  55.15,  $\text{Fe}_2\text{O}_3$  7.18,  $\text{Al}_2\text{O}_3$  4.66,  $\text{MnO}$ ,  $\text{FeO}$ , tr.,  $\text{CaO}$  13.00,  $\text{MgO}$  19.09,  $\text{H}_2\text{O} + 1.60$ ,  $\text{H}_2\text{O} - 0.10$ . Sum 100.78.

PHYSICAL AND OPTICAL PROPERTIES: Color pale gray. Not pleochroic. Luster silky. Biaxial, negative. 2V large.  $\alpha = 1.634$ ,  $\gamma = 1.638$ . Plane of the optical axes parallel to the fibers. Extinction parallel.

OCCURRENCE: Found as a white, asbestos-like mineral in a vein of plagioclase in serpentine, in the region of the Vlasenkov ravine, Beden Mountain, North Caucasus.

RELATIONSHIP: Bedenite is a rhombic amphibole belonging to the anthophyllite series.

W. F. FOSHAG